Limited Blast Resistance In Houses

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FINAL REPORT

Contract No. OCD-PS-64-201

OCD Work Unit 1152H

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Research Report 68-1

Small Homes Council-Building Research Council

University of Illinois at Urbana-Champaign

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IN HOUSES

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OCD Review Notice

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

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SUMMARY

"Limited Blast Resistance in Houses"
Brotherson, Wright & Pecora
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The family shelter idea is by no means new or unique. Since almost two out of three Americans own their own home, a potential exists for providing spaces that can protect the American public from the effects of blast. The amount or degree of protection is dictated mostly by the economic limitations of the homeowner.

For this report, three austere shelters have been developed that will provide protection at the 5 to 10 PSI level. This level of protection was chosen because it seemed that the materials that were needed for the shelter construction were readily available and the process of construction was not beyond the capabilities of the homeowner and one helper. The three designs consist of a wood-frame lean-to, a wood rigid-frame, and a reinforced concrete block shelter. The discussion in this report gives detailed information on the design, construction and erection procedures for each of the three designs.

It is also possible to design a house with the blast shelter and auxiliary spaces as integral parts of the design. To be useful to the homeowner, the "core" area must be of minimal size and the auxiliary spaces must be readily usable for the everyday activities. To illustrate this principle a series of architectural designs are presented in Chapter V. The designs include schemes for the house with basement, without basement, split level design, and for a "total concept" reinforced house. The designs make maximum use of the inherent qualities of the house to provide protection and the shelter areas are integrated into the overall concept of the house. Structural designs are not given since these studies are presented as architectural examples and not as finished designs.

Some homeowners may wish to strengthen their entire house to resist the effects of nuclear explosions. Chapter VI discusses the necessary steps needed to strengthen wood frame houses to the 5 PSI level or other levels of resistance.

The report concludes with a cost analysis of the minimum shelters and a Bibliography of thirty-two references.

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I. Introduction

Almost two out of three Americans own their own homes(6). In the $4,000 to $5,000 income range, 57% are homeowners. As income rises, a greater percentage become homeowners. In the $10,000 - $15,000 range, ownership reaches the 83% level. This high percentage of home ownership indicates that a great potential exists for providing additional protected spaces to shelter the American public in the event of national disaster.

The family shelter idea is by no means new or unique, but most of the civil defense effort in the past few years has been in support of the community shelter. It is true that the community facility can be better stocked and equipped to handle the populace in the event of an emergency. It is also probably true that the population might better withstand the hardships of shelter life with the company of others to bolster morale and provide services that would be impossible in the individual shelter. However, in order for the community facility to be useful to the individual or the individual family, he or his family must be able to reach a facility.

What the probabilities are that this hypothetical individual and his family will be located within reach of a community shelter, and that there will be sufficient capacity for him and his family, is beyond the scope of this report. The fact is, there will be some of the population at home, or near home, when the emergency is called. And, it is possible, with a minimum investment, to provide some degree of protection from the effects of blast and fallout within the home. This sheltered area could be used during the period when blast effects are expected, and then the family could be evacuated to community facilities, or, with expanded habitability features, the shelter could be used for the duration of the emergency period.

The amount or degree of blast protection is limited mostly by the economic desires of the homeowners. For this report, limits have been set to provide blast protection at the 5 to 10 PSI level. The 5 to 10 PSI level was chosen because it seemed that a shelter could be provided that could resist these loadings using material readily available to the average homeowner, and the process of construction is not beyond the capabilities of the homeowner as well. The shelter designs shown in this report were specifically developed so that the homeowner and one helper can build the shelter, thus keeping the expense down to the cost of the materials only.

This report first discusses the response that can be expected from a conventionally-built frame house to the effects of the loadings that will be imposed upon it by a nuclear detonation. This dicussion is a limited one, since complete discussions on the effects of blast loadings can be found elsewhere in the literature.

Following this discussion, three proposed minimum shelters are presented. These are of austere nature and were designed with minimum cost and, as a consequence, with minimum habitability in mind. The inherent capabilities of the house are used where possible to help provide the desired level of protection.

For the homeowner who desires a higher level of livability, a series of designs were prepared that utilize a strengthened or hardened core as the basic shelter area, with adjacent areas of lower protection that can be used as extensions of the basic shelter as the level of hazard is reduced by time or decontamination. Since the strengthened core principle is an integral part of the design of the house, these shelters are presented as part of a total house design rather than as an independent element.

The upgraded shelter, as well as its extensions, are presented as a package; however, the "buyer" may stop at any level of increased protected area or increased livability.

It is also possible that the "buyer" may wish to increase the overall resistance of residential structures to the effects of nuclear explosions. This would require a general strengthening of the entire structure. In many instances, elements of the "conventional" structure have sufficient strength to resist loadings up to 4 PSI.

In most cases, the connections between the elements, i.e., roof to wall, wall to floor, floor to foundation, are the weakest "links" in the chain, and must be revised to increase the strength of the total structure.

It is estimated that the strengthening of homes to the 4 PSI level (this would be about a tenfold increase over the conventional house) would reduce the area of complete destruction from a single weapon down to about 4% of what it would otherwise be (7).*

*Numbers in parenthesis refer to entries in References.

II. Weapon Effects on the Conventionally-Built House

The traditional function of the house is to shelter its occupants from the environment. In this section, the capability of the conventional house to shelter its occupants from the effects of nuclear weapons is discussed, with primary attention given to the effects of blast.

The effects of principal concern are blast, thermal radiation, and nuclear radiation. The intensity of nuclear weapons effects depends upon both the size of the weapon and height of the detonation. The individual concerned with providing shelter has no control over these parameters. Although it is illogical to design to resist the effects of a particular weapon size detonated at a particular point and height, it is possible to provide a consistent level of protection against the various effects. This objective is appropriate because it is grossly wasteful to over-protect against one effect at considerable cost while leaving the shelter occupants vulnerable to the other effects.

The blast wave is a shock, with pressure rising abruptly to a peak value and then decaying more slowly back to normal atmospheric pressure. Two additional effects associated with the blast may also be of importance. Reflection occurs as the shock front strikes an object at nearly normal incidence, and high winds follow the blast front, which cause wind-type forces on objects. The strength of the blast is denoted by the peak overpressure in PSI (pounds per square inch), in excess of atmospheric pressure, which would be exerted on smooth, level ground at the range in question. Figure 1 shows the variation in overpressure at different ranges for small-, medium-, and large-yield weapons. The solid curves indicate the yields for surface detonations and the dashed curves indicate the yield for detonation at a height that maximizes the range to which 5 PSI peak overpressures extend. The term "PSI" is not a familiar one in the house construction field. To give an example, a hurricane wind force of 30 pounds <u>per square foot</u> amounts to just .21 PSI. Five PSI overpressure acting on a roof exerts a force equal to 11 1/2 feet of ponded water.

The human body can resist very high blast pressures, but is likely to be harmed by flying debris, crushed beneath a collapsed structure, or picked up and thrown against a solid element. Therefore, major attention should be given to the effect of blast on the structure, and to keeping personnel out of the path of flying objects and the direct path of the air jets associated with the blast.

The fire hazard arises at a later time than the blast hazard, and, beyond the planning and preparations required to reduce the fire hazard, effective fire protection requires that the occupants be protected from the blast effects so that they are able to prevent fires from going out of control. The range for ignition of residential housing is essentially the same as the range for blast damage. Even then, direct ignition will occur only where there are no opaque objects in the line of sight between the fireball and the building. In many cases, trees, terrain features, or other buildings will provide shielding from direct ignition. As noted later, ignition can be limited by good housekeeping procedures, and there is time between the passage of the blast wave and the beginning of fallout radiation to extinguish small fires. The beginning of the fallout radiation is clearly indicated by deposit of grit and dust from the weapon cloud.

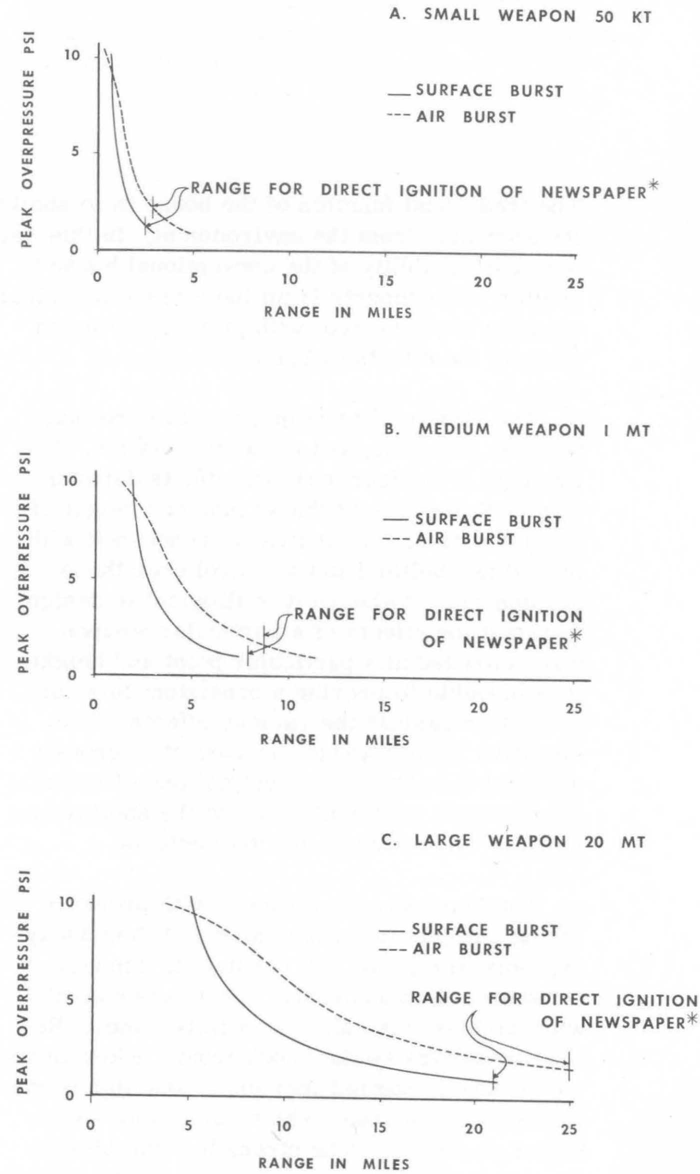
The major initial effect of blast on a house is to tend to crush it. For an ordinary house, the crushing effect is limited because windows break as the blast wave hits the house and pressure inside the house builds up almost as rapidly as that outside. However, the crushing effect is of primary significance for a shelter area, such as the basement, from which the blast pressure is excluded by strong, tight coverings over all openings.

At a range where the peak overpressure is 1 PSI, the blast damage to a well-constructed conventional house may consist of door and window breakage, with some displacement of lightly fastened interior partitions and furnishings. Although structural damage is superficial, there is a relatively severe hazard to unsheltered occupants from flying glass and other debris.

The blast wave is reflected when it strikes an object, such as a wall of a house. This reflection causes a temporary increase in the overpressure by a factor of 2.1 for 1 PSI to 2.5 for 10 PSI peak overpressures. The reflection effect, and the sweep of the blast front over the house, lead to a tendency for the house to be pushed or translated in the direction away from the point of detonation. The winds associated with the blast add to this effect. For 10 PSI peak overpressure, peak wind or dynamic pressure is 2 PSI. It drops to .55 PSI at 5 PSI overpressure, and at a lower peak overpressures the structural significance of the dynamic pressure is slight.

The house is most sensitive to the horizontal forces of the blast--the direct pressures on exterior panels and translational forces that occur as the blast wave envelops the house. The traditional design loads--weight of building, snow, furnishings, etc.--are essentially vertical. Except in those geographical areas subjected to severe winds or earthquakes, little attention is given to horizontal forces in house design. For blast loading, the pressure on the windward wall exceeds the pressure on the roof, and the peak horizontal force can easily exceed the weight of the house. The windows and doors are most sensitive to blast. As the pressures increase, the walls fail where weakened by openings, interior partitions are broken, and roofs and floor systems are damaged, until total horizontal resistance is overcome and collapse of the structure occurs.

The dimension of these loads can be realized by considering a wall of a house 12 feet high, 40 feet wide, and 25 feet deep being struck on the wide face by the blast wave. At 1 PSI peak overpressure, the peak translational force would be 145,000 pounds. At 5 PSI, this force would equal 830,000 pounds, and, at 10 PSI, the peak translational force would be 1,870,000 pounds. For comparison purposes, hurricane



* ASSUMING NO SHIELDING IN LINE OF SIGHT TO FIREBALL

RANGES OF NUCLEAR WEAPONS EFFECTS

Figure 1

winds of 100 miles per hour, with a drag coefficient of 1.0, would result in translational forces of about 12,000 pounds. If the house itself weighs approximately 50 pounds per square foot of plan area, the total weight would be 50,000 pounds. The blast-induced translational forces may exceed the weight of the house by a considerable amount. This peak translational force falls off very rapidly, and is decreased by the entrance of the blast wave through windows, the decay of reflection on the front face, and the build-up of pressure on the back face. The translational force will fall from its maximum value to essentially zero in a time of about .06 seconds for the house just considered. Its effect is, therefore, more like a blow than a push. For below-ground shelters, the whole translational loading factor is avoided.

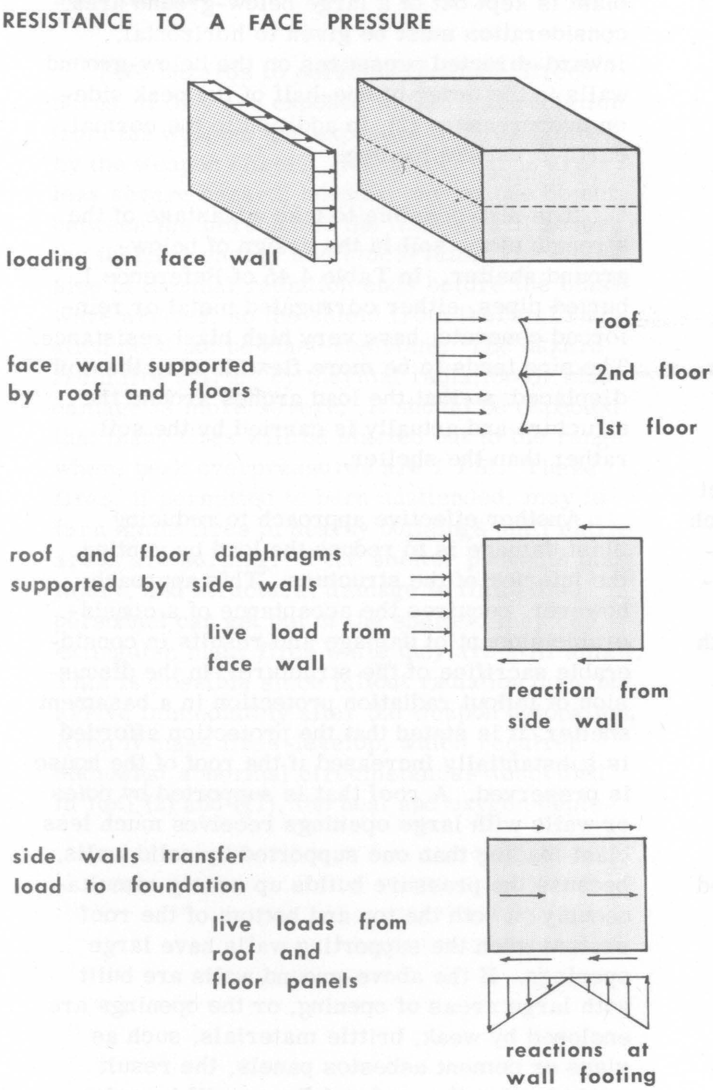


Figure 2

When considering means for obtaining blast-resistance in houses, it is important to understand the fundamental causes of weakness. Blast is a dynamic force, and its intensity varies with time. Toughness or ductility is as important as static strength in resisting the effects of blast. Brittle material, such as glass or unreinforced masonry, is most susceptible to damage. Tough materials, such as ductile metals and well-connected timber, are able to yield under the peak forces and actually can survive peak pressures higher than their static resistance. Most structural materials have high ductility and good inherent blast resistance.

For the short duration of blast loadings, the strength of building materials is greater than for conventional long-duration loads by about 25% for mild steels, 50% for concrete, and 200% for timber.

The major cause of failure under blast conditions in the conventionally-built house is generally the inadequate interconnection between the structural elements. When strengthening conventional houses, first attention should be given to improving the connections so as to take advantage of the inherent strength. The means by which lateral pressure acting on an exterior wall is transferred to the foundation is shown in Figure 2. A two-story house is shown in the example, but the concept of the behavior is valid for single- or multi-story structures. Pressure acting on the wall panel is carried by the beam action of the wall and is resisted by the roof and floors acting as horizontal deep beams or diaphragms. The horizontal diaphragms are supported by exterior or interior walls, acting as shear walls, which transfer the load to the foundation. The direction of the blast wave is unpredictable, so all exterior walls must be able to act as either slabs spanning between floors or as shear walls supporting the floor diaphragms.

The structural system just outlined has substantial inherent resistance when the walls and floor panels are conventionally constructed, if connections between the elements are adequate. Each interface is a zone of potential weakness that could waste the reserve strength elsewhere in the system. Walls should be connected to roofs and to floors to transfer forces normal to the wall (these occur when the wall is subjected to normal pressure and could be directed either inward or outward), and to transfer forces parallel to the wall (these occur when the wall acts as a shear wall supporting the floor or roof diaphragm). Walls should be connected to the footings to resist shear normal to the wall (for normal pressure on the wall), shear in the plane of the wall (shear wall action), and vertical forces in the plane of the wall (beam action forces of the shear wall) that may be either tensile or compressive.

The vertical forces from blast are not the principal cause of damage, because conventionally constructed houses provide resistance to gravity forces. However, the vertical forces caused by the blast pressures are very high when compared with conventional loads. Design or construction defects which would be unimportant under conventional loads may result in premature failure under blast-loading conditions. The resistance of surface panels to normal blast pressures is sharply increased as the spans of the panels are reduced, and firm connection or continuity over supports can substantially increase the strength by membrane action. Supporting walls or columns should be continuous from roof to foundation. Offsets of walls or columns are likely to be weak points where the shear capacity of the connection is inadequate to develop the bearing capacity of the wall or column.

Uplifting loadings can also accompany the blast. Although these are usually much smaller than the vertical forces acting down on the structure, they may cause substantial damage unless the structural elements of the house are strongly interconnected. It is difficult to predict the uplift loadings, so a "rule of thumb" approach to the design of hold-down connections is justifiable. If a simple detail can be used that will develop the strength of the panel in uplift, such a connection should be provided. If a full-strength connection is not feasible, an effort should be made to provide a connection capable of developing at least one-half the strength of the panel. The provision in the design for uplift forces is also of great value for the severe wind loads, as well as for the blast loads.

Blast loadings on structural elements located flush with or below the ground surface are reduced because dynamic pressures do not occur, and the irregular build up of overpressure reduces the effect of reflection. The small basement shelters designed in this report are detailed to resist a nonuniform pressure distribution with peak pressures of 10 PSI. This level could be attained at a peak side-on overpressure (Figure 1) of 4 PSI if the blast wave was fully reflected onto the shelter. Most often, the shelter would not be subjected to a classical shock wave, and the shelter would survive at ranges where peak side-on overpressures approach 10 PSI. These designs assume that conventional basement walls would resist the blast loadings. For a small shelter in a blast-vented basement, pressure would build up inside the basement as it built up in the soil outside of the wall. Only the small area of wall serving as wall to the shelter would be likely to have blast-induced external pressure tending to drive the wall in without the counteracting effect of inside pressure. Since the wall spans two ways--between shelter top and floor, and between shelter ends, it is unlikely to be the weakest link. For shelter designs in which blast is kept out of a large below-ground area, consideration must be given to horizontal, inward-directed pressures on the below-ground walls in the order of one-half of the peak side-on overpressure (2), in addition to the normal earth-pressure loading.

It is also possible to take advantage of the strength of the soil in the design of below-ground shelter. In Table 4.45 of Reference 1, buried pipes, either corrugated metal or reinforced concrete, have very high blast resistance. The pipe tends to be more flexible than the soil displaced, so that the load arches around the structure and actually is carried by the soil rather than the shelter.

Another effective approach to reducing blast damage is to reduce the load by venting the interior of the structure. This approach, however, requires the acceptance of a considerable amount of damage and results in considerable sacrifice of the structure. In the discussion of fallout radiation protection in a basement shelter, it is stated that the protection afforded is substantially increased if the roof of the house is preserved. A roof that is supported by poles or walls with large openings receives much less blast loading than one supported by solid walls, because the pressure builds up nearly simultaneously on both the top and bottom of the roof system when the supporting walls have large openings. If the above-ground walls are built with large areas of opening, or the openings are enclosed by weak, brittle materials, such as glass or cement asbestos panels, the result would be that the roof and floors will be only lightly loaded. The above-ground contents of the house will be severely damaged by the blast wave, but the benefits obtained in the basement shelter may justify the sacrifice.

Fire must also be considered when designing the shelter area--both from the direct thermal radiation from the fireball, and from the secondary effects of blast damage. Approximately one-third of the energy of the nuclear weapon is immediately released as heat. The heat given off is sufficient to ignite newspaper, at the ranges shown in Figure 1. when atmospheric conditions of ten miles visibility are present, and when there is an unrestricted line of sight from the fireball. The fire hazard is unlikely to exist beyond these ranges. Appliances and utilities damaged by the blast wave also are likely to start fires.

Fire hazards to personnel include direct burns, if they are exposed to thermal radiation from the weapon, and exposure to fires ignited by the weapon effects. The direct burns are a less severe hazard, because any opaque object between the person and the fireball will absorb the thermal energy and shield him. The emission of thermal radiation ends before the blast wave arrives, so the shield from thermal radiation need not be blast-resistant. The hazard from fire started by thermal radiation or blast damage is more severe. It should be expected that many fires will be started out to the range where peak overpressures are 1 PSI. These fires, if permitted to burn unattended, may in turn ignite fires in nearby buildings until entire areas are burning. If the shelter prevents blast injury, and structural damage is limited so personnel can get out of the shelter, they can extinguish many fires while they are still small. This is possible since fallout radiation does not arrive immediately after the weapon detonation. Even if mass fires develop, which requires somewhat abnormal circumstances described in Ref. (2) and (11), the heat and oxygen depletion will seldom be so severe that people cannot evacuate the area.

The last of the major effects to reach the shelter occupants will be that of the fallout radiation. Fallout radiation does not damage the structure, but it provides a severe hazard to the occupants. There are two principal sources of nuclear radiation--the initial radiation directly from the weapon, and the fallout radiation emitted by materials that have been drawn into the fireball and mushroom cloud and fall back to the earth after the explosion.

It is not possible to describe the total radiation exposure as a simple function of distance from the weapon. Too many unpredictable variables effect the distribution of the fallout. Initial radiation is negligible at ranges appropriate to overpressures of 10 PSI or less for weapon yields of 1 MT or greater. Fallout radiation is negligible for weapons detonated as air bursts, but can be severe from weapons detonated at or near ground surface. Where fallout does occur, it first is carried to extremely high altitudes (sometimes as much as 50 miles) by updrafts in the mushroom cloud and then takes time to fall back to earth. The arrival of fallout radiation is visibly apparent, since early fallout has the appearance of coarse to fine sand. The wind direction and wind velocities at different altitudes will affect the area distribution of these particles. The highest levels of radiation are in those particles which fall within a few hours after the explosion, so personnel in the open should be on the alert to watch for visible signs of early fallout.

On the basis of data in References (1) and (3), for purposes of this report, a fallout protection factor of 100 is considered to be consistent with blast protection in the range of 1 to 10 PSI. To provide protection factors of 100, special shelter area construction features will be needed (12).

III. Shelters

The discussion in the previous section stated that a shelter providing protection against nuclear weapons effects must provide consistent levels of protection against blast, nuclear radiation, and fire. It must also remain habitable for the necessary period of use, and must be readily accessible when needed. It must also provide an exit from the shelter, with consideration given to the blast and fire damage of the surrounding structure or structures. The requirements for blast and radiation protection in the above-ground or below-ground shelter are different, while habitability and fire protection are approximately the same for either type of shelter. In either case, the inherent strength and protection of the conventional house structure should be exploited so that shelter can be provided at minimum increase in cost.

It is very difficult to provide the requirements for a blast shelter in a large above-ground area and still meet the architectural requirements for a house to be suitable for normal living conditions (one such example is given later in this report). Windows and doors will break at low overpressures and allow the blast and the projectiles created by the blast to enter the house. Although the blast-vented house is not in itself an adequate shelter, strengthening the basic house structure so that it will not collapse under the blast load can contribute to the effectiveness of a shelter within the house. Considerable strengthening is provided by improved connections between conventional elements, such as the floor system to the foundation, the exterior walls to the floor, and the roof system to the exterior walls. Examples of improved connections are shown in Chapter VI of this report. If the basic house structure remains in place, the fire hazard to occupants of the shelter is likely to be reduced and radiation shielding is improved, because even a racked and leaking roof will keep much of the fallout out of the structure and away from the shelter.

Blast and radiation protection in an above-ground shelter in a conventional house requires that a substantial amount of construction be built around the shelter area. To provide radiation protection with a factor of 100 in a shelter 8'-0" wide by 10'-0" long by 8'-0" high, the wall construction would necessarily be of reinforced concrete 18 inches thick, and the roof thickness would be at least 15 inches thick. If a single-story house of a normal frame construction remains in a place around the shelter, the required thickness of a shelter roof area can be reduced to 12 inches and the walls to 15 inches. With this thickness of concrete required for radiation shielding, blast resistance is easy to obtain. Reinforcing mesh of a size adequate to control shrinkage and temperature cracking (about .25% steel in each face of walls and roof) will give the required blast resistance. Doweling is required to connect the shelter walls to the foundation.

It is almost as difficult to keep the blast out of the basement as it is to keep it out of the above-ground parts of the house. The windows in the basement walls are subject to breakage by low overpressures, and, if windows are absent, a substantial problem remains in providing blast-tight closures for all entrances to the basement. This approach appears to be extremely expensive, and the use of blast-vented basement areas seems to be a better approach.

The radiation shielding requirements in a basement shelter depend substantially upon the degree of blast damage to the house above. A basement shelter, 8'-0" high, 8'-0" wide and 10'-0" long, located in the corner of the basement, requires a 4" concrete roof and 4" concrete walls if the house remains in place above the shelter, keeping most of the fallout off the first floor. The required wall and roof thickness will increase to 6" if only the first floor remains following the blast, and to 9" if the blast leaves the basement completely exposed to the fallout.

If the shelter is located below-ground, adjacent to the basement wall, excellent radiation protection can be achieved by the shielding affect of the surrounding soil. For an 8'-0" wide by 8'-0" high by 10'-0" long shelter with 2'-0" of earth cover over the roof area, and the smaller dimension facing the adjacent basement wall, a protection factor of 100 can be obtained at the middle of the shelter using a closure wall between the basement and the shelter of a thickness equivalent to 8" of concrete, even if the basement is fully contaminated. If the exposure to the basement is reduced, the protection factor would be further increased.

In addition to providing protection against the harmful effects of radiation and blast, the shelter must also provide a tolerable environment for the duration of the stay within the shelter. Requirements for food and water supply, sanitation, and ventilation are described in References (5) and (13) for fallout shelters. The requirements are appropriate for shelters for either fallout or blast, because it is the fallout that requires a sustained occupancy of the shelter. However, the blast shelter has somewhat more severe environmental problems associated with fire and the hazards from damaged utilities.

The best method of defense against fire is to try to prevent its occurrence by design and maintenance. Reference (1) illustrates, with actual nuclear test experience, how the maintenance of the house exterior and surrounding area can extinguish fire started by the thermal radiation pulse. This is done by depriving the fires of fuel. The selection of fire-resistant materials for drapes, shades, and other susceptible interior furnishings also is desirable. Highly flammable supplies, such as paints, gasoline, and oil, should be stored in a manner that will minimize spillage from blast damage. Utilities damaged by the blast can contribute major amounts of fuel. Careful utility layout can also minimize the damage from blast. Provision must be made within the structure so that utilities can be turned off during an alert or immediately after the blast.

Even if the blast damaged house burns, or a mass fire occurs, survival in the fire area is still possible. As described in Reference (14), the direct hazards are excessive temperatures and the presence of smoke and toxic gases. Oxygen depletion is not too much of a problem since the oxygen concentration required to sustain a fire is greater than that required for survival of people.

The substantial walls and roof required in a shelter for radiation shielding provide considerable protection from the high-temperature effect of fire. Smoke and toxic gases can be minimized by using a hand-cranked blower on a ventilation duct with the air intake located near the ground surface and at least 10 feet from the house or other objects containing a large amount of combustible material. The air intake should have a hood over it to keep out fallout radiation particles. In general, a hood which will keep out rain will also keep out fallout, and no special filters are required. As a last resort, the shelter may be sealed up until the fires burn out. The air volume normally provided inside shelters is adequate to outlast most fires. Furthermore, as soon as the blast wave has passed, the occupants may go outside and assess the situation from the standpoint of fire hazards.

Blast damage sometimes reduces the fire hazard rather than making it more severe. The blast may blow out many early ignitions, since it arrives later than the thermal pulse. Also significant is the possibility that blast may blow away portions of the house which contribute heavily to available combustible materials. Where the shelter is in the basement, sacrificing some of the above ground portions of the home may improve the chances for survival. Once a fire has started, it will spread most rapidly in buildings which are only slightly damaged by blast, that is where the buildings are standing but doors and windows are blown out. Buildings which are completely demolished by blast may be expected to burn slowly or not at all. Although debris from a house severely damaged by blast might make exit from the shelter difficult for occupants threatened by fire, it is quite likely that debris will be blown off site rather than deposited in the basement.

Careful attention must also be given to the drainage of below-ground shelters. Electric sump-pumps are likely to be undependable during shelter occupancy. If gravity drainage is not available, then a hand-pump should be provided, so that the occupants are not driven out of the shelter by rising water.

IV. Minimum Shelters

As stated earlier in this report, one of the main objectives of this investigation was to develop a family blast shelter that could be constructed as inexpensively as possible. The essential criteria used for the shelter design are as follows:

1) The shelter must be able to resist an equivalent static load of 10 PSI for short periods.
2) The shelter must provide protection from fallout radiation.
3) The shelter must provide protection from the effects of missiles generated by the blast wave.
4) The shelter must be designed so that it can remain habitable during the e emergency period.

In order to meet the first criterion, the shelter must be able to remain standing without failure after the blast wave has passed. Cracking or deflection of the shelter can be tolerated as long as complete failure does not occur. To provide protection under the second criterion, the shelter must have a high mass-thickness to provide radiation shielding, and must be located so that maximum advantage is taken of the distance between the radiation field and the shelter. If the first two criteria are met, the third criterion, protection from missiles, will be easily met. The habitability criterion is more difficult to meet. Habitability will not be covered in depth in this report, since other areas of the literature cover habitability adequately(5).

The first step in this study was to investigate those shelter designs already available through the Office of Civil Defense. The underground backyard shelter seemed to be the best design to provide protection from the effects of blast and fallout. However, because of the limitations of site conditions, drainage, sanitation, and possible misuse, the underground backyard shelter was eliminated from consideration. The shelter located in the basement of the house was selected as the best type, since it would alleviate most of the problems associated with the underground backyard shelter, and the maintenance and control of the shelter could be more easily achieved.

The shelters available for family occupancy, while providing protection from the effects of fallout and debris, were not designed to withstand any substantial blast pressures. In order to provide a variety of choice of design, and flexibility in meeting the various conditions, three types of shelters were designed that would withstand the effects of blast and fallout radiation:

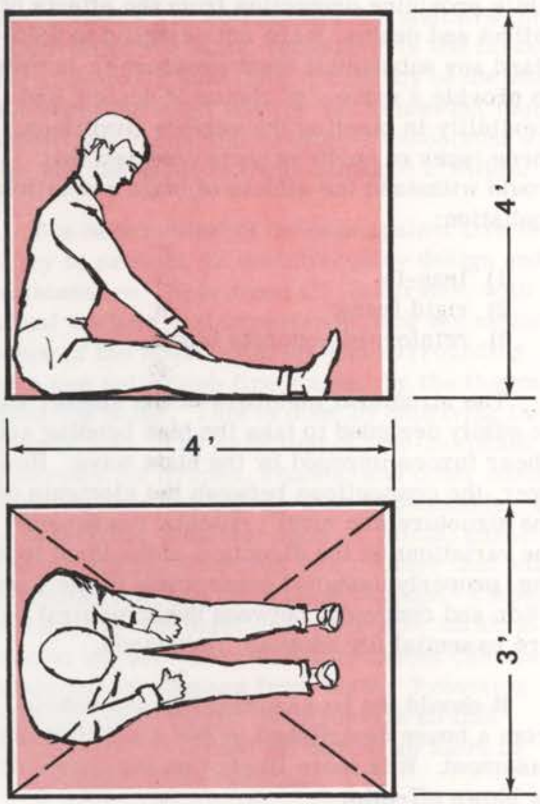
1) lean-to
2) rigid frame
3) reinforced concrete block

The structural members of the shelter can be easily designed to take the high bending and shear forces imposed by the blast wave. However, the connections between the elements of the structure are most critical. Because of the variations in the direction of the blast loading, properly designed connections to the foundation and continuity between the structural parts are essential for adequate resistance.

It should not be assumed that the debris from a house demolished by blast will fall into basement. It is more likely that the debris will be blown off-site.

Besides providing the required blast resistance and radiation shielding within the shelter, the shelter must also be planned and designed so that it can be easily constructed by the average homeowner. The shelters presented in this report have been developed so that they can be constructed by two people, using readily available tools and materials. Lumber and wood products are the easiest materials to handle and fabricate because of their relatively light weight and easy workability. On the other hand, cast-in-place concrete is a very impractical material for the average homeowner to use because of the complexity involved in obtaining the correct concrete mixes, handling and placing of the concrete, the placing of reinforcing steel, and the difficulty in getting pre-mixed concrete into existing basements. Concrete block construction can be considered since only a minimum amount of skill is needed to build with block, or the necessary labor may be hired.

For the most part, the designs presented in this section make full use of the advantages of prefabrication of the units used in the construction of the shelters, and make use of an expandable module that can be added to the shelter to increase the capacity as the needs of the family vary.

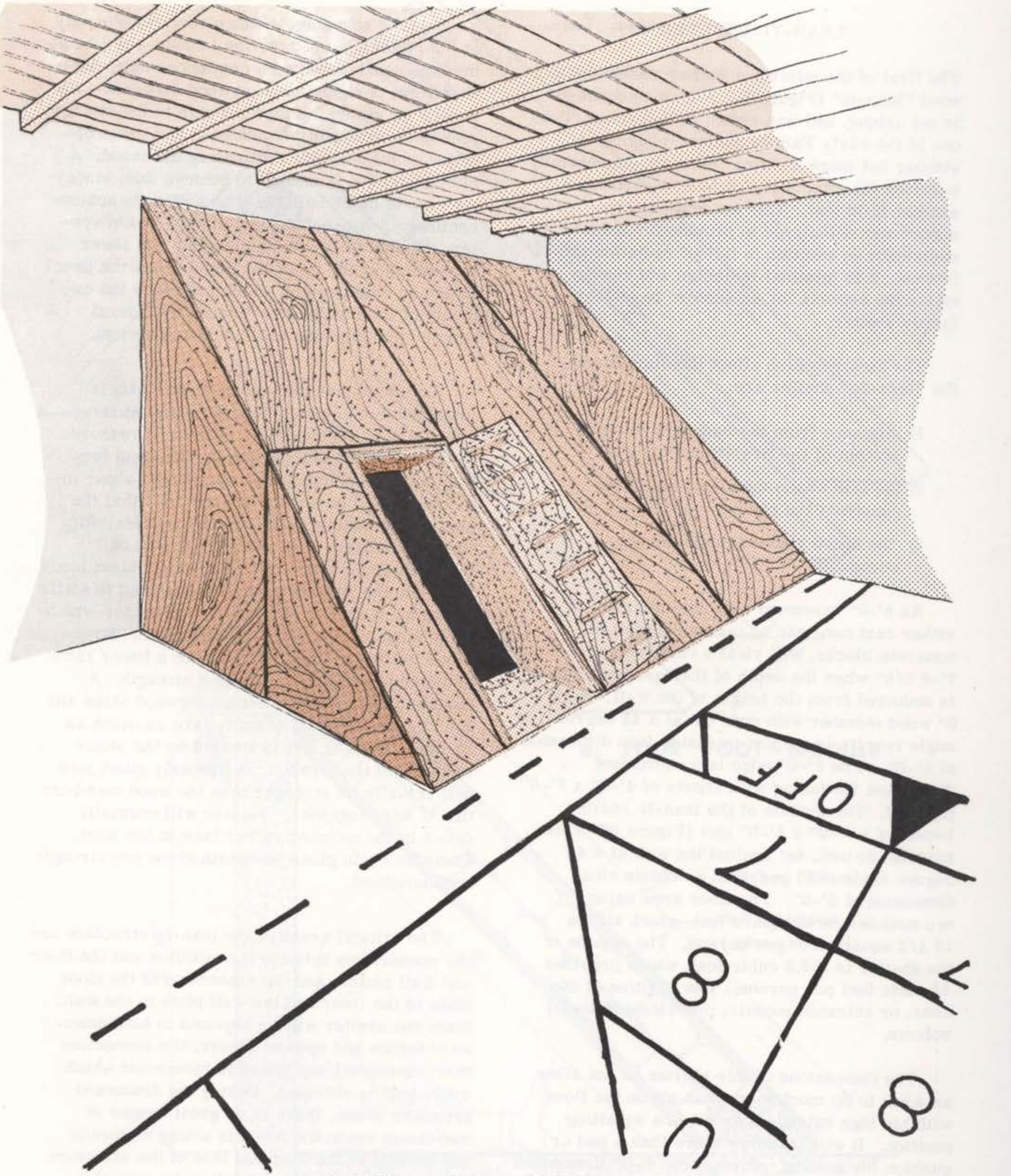


Space Requirements

Figure 3

The survival of the shelter occupants is the main concern of this study, and, therefore, the human environmental requirements are very important. Each shelter occupant must be furnished with sufficient floor area and volumetric space. The duration of the occupancy after the attack will be a main factor influencing the dimension of the space requirement. The shelters presented in this report are considered as minimum, and therefore have been designed with austerity as a main consideration. It is anticipated that the basement shelter will sometimes be used as a primary emergency area, and, after the initial hazards are over, the occupants may consider moving to community shelters or multiple-family shelters with higher degrees of habitability and radiation protection. However, since the move to the community shelter may not be always possible, these shelters must also provide minimum requirements for an extended stay within the shelter. If the house is not located within the high overpressure areas, it probably will still be standing after the passage of the blast wave, and the family or occupants of the shelter could possibly move into the adjoining basement areas for short periods of time. However, if the house above the shelter is completely destroyed, the family is left with only the shelter as a habitable area. In this case, the shelter must function as the family's only living quarters until the level of radiation has decayed sufficiently or the area adjacent to the shelter area can be decontaminated. Since exposure to radiation for short periods of time is feasible, the occupants may leave the shelter for elimination of human waste, for limited exercise periods, and for decontamination of the basement area.

The shelters presented in this report are considered "three-person shelters," allowing for either three adults or two adults and two children. Figure 3 illustrates the amount of floor area and volumetric space that would be required by an adult allowing himself to kneel or sit with his legs extended in a reasonable amount of comfort. This volume, 3'-0" wide x 4'-0" deep x 4'-0" high, provides 48 cubic feet per person, which is somewhat under the current O.C.D. minimum recommendations of 65 cubic feet. Auxiliary spaces within the shelter could provide an additional 17 cubic feet.



LEAN – TO SHELTER

Figure 4

LEAN-TO SHELTER

The first of the minimum shelter designs is a wood "lean-to" (Figure 4). A lean-to concept is not unique, and was shown in Reference (4) as one of the early Family Shelter designs. A similar but more austere "lean-to" successfully survived the effects of a nuclear weapon in a nuclear field test. This concept has been redesigned and reanalyzed to provide for blast resistance in addition to fallout radiation protection. It is minimal in design and readily meets the criteria for an austere basement family shelter.

The factors which affect the dimensions of the "lean-to" shelter are:

1) distance from the basement floor to bottom of the first-floor joists
2) the size of the members needed to construct the shelter
3) the space requirements for the occupants.

An 8'-0" basement wall construction, of either cast concrete or twelve courses of concrete blocks, will yield a clear height of 7'-9 5/8" when the depth of the basement slab is deducted from the height of the wall. A 10'-0" wood member with ends cut at a 45 degree angle results in a short or inside face dimension of 8'-0". The 8'-0" edge is a convenient dimension for facing with sheets of 4'-0" x 8'-0" plywood. The module of the lean-to shelter becomes a 4'-0" x 8'-0" unit (Figure 5). This module or unit, set against the wall at a 45 degree angle, will result in an inside clear dimension of 5'-8". The floor area using two modules is 46 square feet, which allows 15 1/2 square feet per person. The volume of the shelter is 134.5 cubic feet, which provides 45 cubic feet per person. The addition of the door, or entrance module, provides additional volume.

The dimensions of this shelter do not allow an adult to do much more than sit on the floor with his legs extended, or sit in a squatting position. It will not allow more than a pad or cushion for seating, although the 5'-8" dimension is enough to provide a sufficient amount of leg and head room. The additional space provided in the toe of the lean-to can be used for stocking supplies or extra sandbags.

To take advantage of the structural integrity of the materials used for the lean-to, the module must be constructed as a continuous unit, and is, therefore, designed as a plywood stressed-skin panel. By gluing the plywood skin to the stringer members, continuity is achieved and the properties of the stringer section are enhanced. A gluing process is needed to achieve this, since the glue is more reliable than nailing to achieve continuity. A panel using a stressed-skin system not only improves the bending and shear properties of the panel but also causes the panel to act as a diaphragm, which improves the capacity of the shelter to withstand the lateral forces from the side walls of the basement.

An analysis of the stressed-skin panels indicated that 3/4-inch plywood skins were necessary to resist 10 PSI peak overpressures. A static ultimate strength (qy) was found for bending, horizontal shear, and rolling shear in the section. The actual dynamic load that the section can take is influenced by the flexibility of the members. The section's period of vibration and the time duration of the blast loads influence the ratio of peak dynamic load to static strength. It is also necessary to consider whether bending or shear will cause failure. Structures tending to fail in shear have a lower ratio of dynamic resistance to static strength. A module design using 3/4-inch plywood skins and 2 x 12 stringers will actually take as much as 20 PSI in bending, but is limited by the shear capacity of the plywood. A properly glued joint will actually be stronger than the wood members that it joins together. Failure will normally occur in the member rather than in the joint. Phenolic resin glues or casein glues are strongly recommended.

The critical areas of the lean-to structure are the connections between the modules and the floor and wall plates, and the connection of the floor plate to the floor and the wall plate to the wall. Since the shelter will be exposed to both downward forces and upward forces, the connection must counteract any possible movement which could lead to collapse. During the downward pressure phase, there is no great danger of movement since the force is acting uniformly and normal to the diagonal face of the structure, and the load is transmitted directly into the basement wall and floor. A major portion of the force reaction is transferred directly by bearing, causing a wedge action.

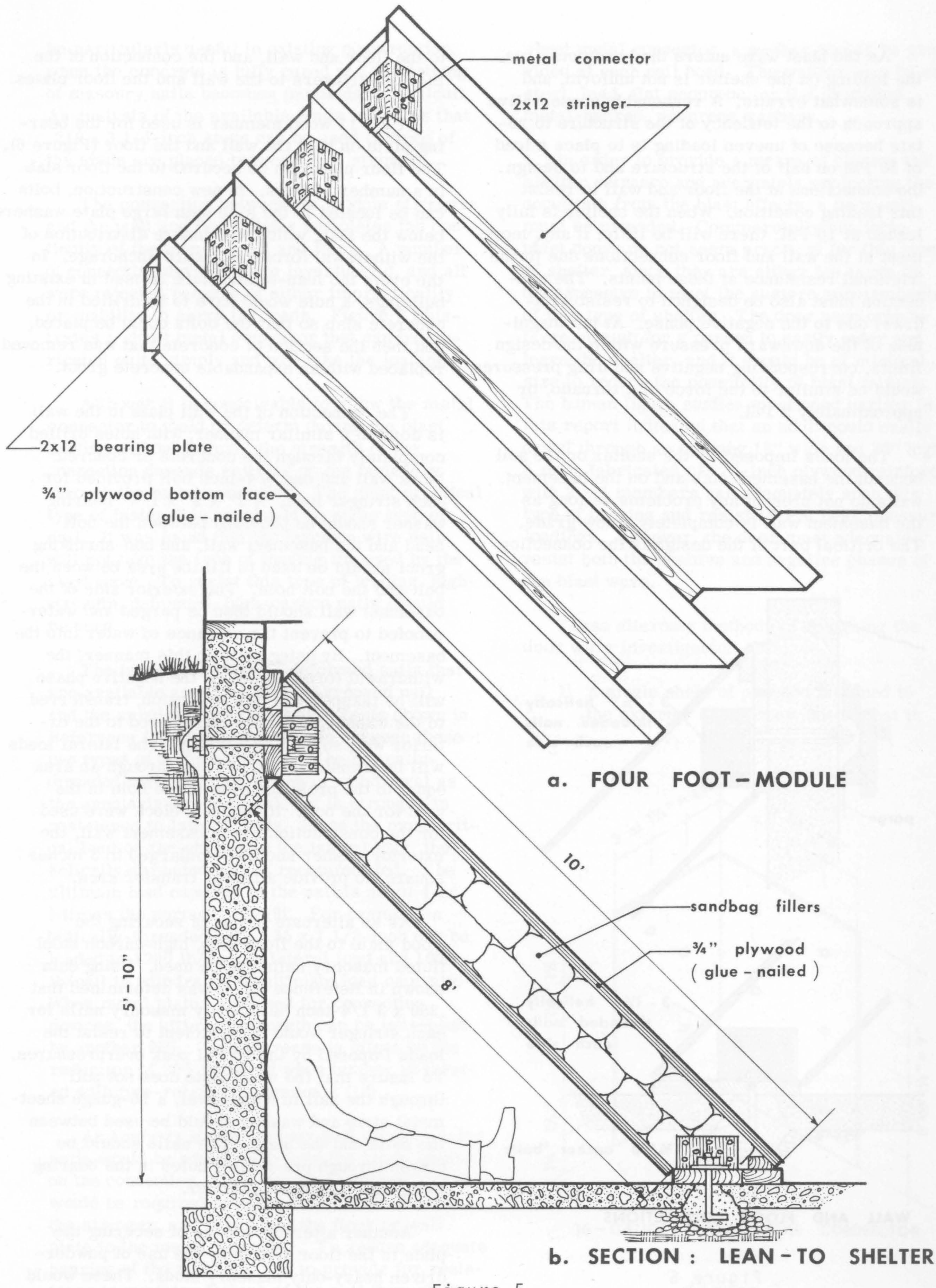
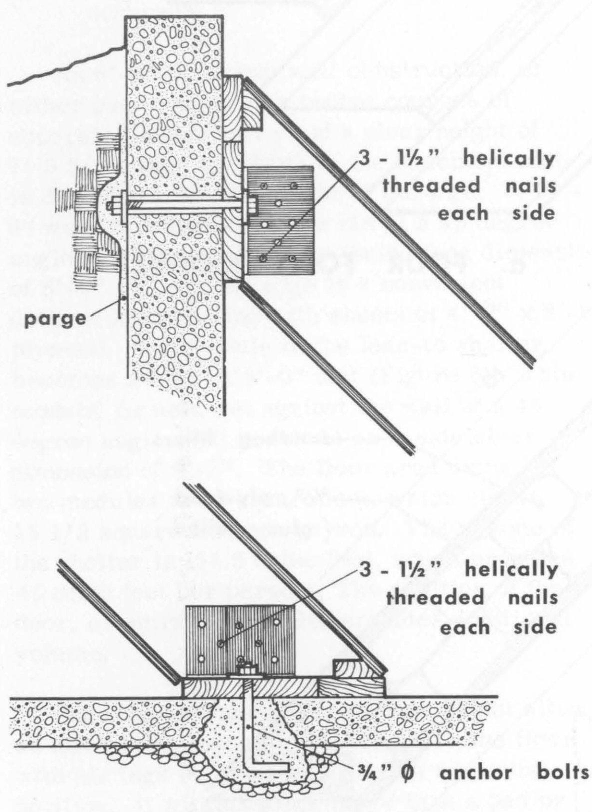

metal connector
2x12 stringer
2x12 bearing plate
¾" plywood bottom face
(glue nailed)
a. FOUR FOOT-MODULE
10'
sandbag fillers
¾" plywood
(glue - nailed)
8'
5' - 10"
b. SECTION : LEAN-TO SHELTER

Figure 5

As the blast wave enters the basement area, the loading on the shelter is not uniform, and is somewhat erratic. A reasonably conservative approach to the tendency of the structure to rotate because of uneven loading is to place a load of 10 PSI on half of the structure and to design the connections at the floor and wall to resist this loading condition. When the shelter is fully loaded at 10 PSI, there will be little, if any, movement at the wall and floor connections due to the frictional resistance at these points. The connection must also be designed to resist withdrawl due to the negative phase. At the magnitude of the downward pressure within the design limits, corresponding negative and drag pressures would be similar to the force of a tornado, or approximately 2 PSI.

The loads imposed by the shelter on the soil beneath the basement slab and on the basement walls do not present any problems as long as the basement wall is completely below grade. The critical part of the design is the connection to the floor and wall, and the connection of the module stringers to the wall and the floor plates.



WALL AND FLOOR CONNECTIONS

Figure 6

A 2 x 12 wood member is used for the bearing plate on both the wall and the floor (Figure 6). The floor plate can be secured to the floor slab in a number of ways. In new construction, bolts can be located in the slab with large plate washers below the slab, which will insure distribution of the withdrawal force and insure anchorage. In the event the lean-to structure is used in existing buildings, a hole would have to be drilled in the concrete slab so that the bolts could be placed, and then the section of concrete that was removed replaced with an expandable concrete grout.

The connection of the wall plate to the wall is done in a similar manner, with holes drilled completely through the concrete or concrete block wall and one 3/4-inch bolt provided for each stringer load. A 2" x 2" x 1/4" bearing washer should be provided between the bolt head and the basement wall, and non-shrinking grout should be used to fill the area between the bolt and the bolt hole. The exterior side of the basement wall should then be parged and waterproofed to prevent the entrance of water into the basement. By using bolts in this manner, the withdrawal force caused by the negative phase will be taken in the bolt in tension, transferred to the washer, and then transferred to the exterior wall surface in bearing. The lateral loads will be transferred in bearing through an area equal to the projected area of the hole in the wall for the bolt. If concrete block were used for the construction of the basement wall, the exterior washer should be enlarged to 3 inches square, to provide a larger transfer area.

As an alternate means of securing the wood plate to the floor slab, high-carbon steel fluted masonry nails can be used. Using data shown in Reference (8), it was determined that .250 x 3 1/4-inch heavy-duty masonry nails for each stringer would be sufficient to resist the loads imposed by the 10 PSI peak overpressures. To insure that the wood plate does not pull through the nail in withdrawal, a 16-guage sheet-metal strip and washer should be used between the nails and the plate. The nails should be driven through pre-drilled holes in the bearing plate with a 6-pound hammer.

Another alternate means of securing the plate to the floor slab is by the use of powder-driven heavy-duty masonry studs. These would be particularly useful in existing construction, when the concrete is fully cured and the driving of masonry nails becomes particularly difficult. An analysis of the available studs indicates that .219 x 3 1/4-inch studs can be used if three of the studs are placed between each stringer.

The connection between the module stringers and the wall and floor plates completes the continuity of the lean-to wall and floor. A number of connecting devices were investigated, and all were rejected because of either impracticality or inability to carry the loads. Figure 7 illustrates a sheet metal connector that can be fabricated quite simply and will take the loading.

Although it is conceivable to allow the metal connector to yield or deform during the blast loading without failure, the strength of the connection depends entirely on the fasteners through the metal connector. The most practical type of fastener to use would be some type of nail. It was found that the common wire nail will not take the type of loading imposed by the blast wave. To resist this type of loading, high-strength, deformed, high-carbon nails should be used.

The two major types of deformed nails that are available are the helically-grooved nail and the annularly-grooved nail. Tests shown in Reference (8) give a comparison between these two types of deformed nails. The helically-threaded nail is not as strong in withdrawal as the annularly-grooved nail, but is stronger in resistance to lateral loads. Since the most critical load on the shelter is the lateral load, the helically-threaded nail is recommended. The ultimate load capacity of the nail is about 4 or 5 times the normal value(9). For example, a helically-threaded nail .135 x 1 1/2-inch can be loaded to 1200 lb/nail in lateral load and 1000 lb/nail in withdrawal at ultimate load capacity. When metal plates are used for connecting devices, the ultimate strength can be increased by another 25%. This increase is offset by the reduction of 25% required when lumber is treated with fire-retardant chemicals (10).

An analysis shows that six helically-threaded nails would be adequate to take the loads imposed on the connection. Two groups of six nails each would be required to connect the metal plate to the stringer, and to connect the floor or wall plate to the metal connector. To assure adequate bearing of the nail head and to provide for resistance to punching failure of the nail through the sheet metal connector, a washer should be provided at each nail head. The washer may be of steel, lead, flat neoprene, or flat or dished, metal-backed, neoprene washers.

In order to provide a means of closing the shelter entrance and adequately protecting the occupants from the blast effects, a door unit must be provided. Commercially available blast doors do not seem practical for this type of shelter, since they are either too large or too expensive to meet the austere requirements of this type of shelter. The door need only be large enough for a person to easily enter and leave the shelter, and it should be of minimal size to reduce the possibility of blast failure. The human figure studies mentioned earlier in this report indicated that an adult could easily crawl through an opening 18" wide and 30" high. A door fabricated of 3/4-inch plywood reinforced with 2 x 4 members can adequately span this type of opening and resist 10 PSI peak pressure loadings. However, the door must adequately resist both the positive and negative phases of the blast wave.

These alternate methods of designing the door were investigated:

1) A single sheet of plywood fastened to the exterior of the door unit so that it

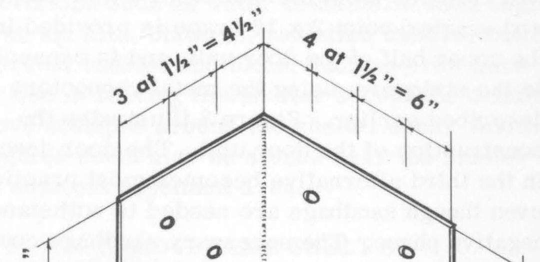


Figure 7

can withstand both the negative and positive phases.

2) Two doors, one on the outside of the door unit, and one on the inside of the door unit, designed so that the outside and inside doors take the positive and negative phases by bearing against the door unit stringers.

3) One exterior door backed by sandbags. The exterior door would withstand the positive phase, and probably would be torn off by the negative phase, leaving the sandbags to provide protection during this period.

In all three, sandbags will be required for fallout protection at the door opening, since the plywood door lacks the mass needed to provide radiation protection.

The design study indicated that it was impractical to install a door in the side wall of the shelter. By adding half of a shelter module, the fitting of the shelter door can be facilitated, and the additional volume created by the half module can be added to the environmental requirements of the shelter. The door unit is similar in construction to the lean-to unit. The 2 x 12 stringers are doubled around the opening to increase the strength of the unit so that it can withstand lateral forces from the side wall. To provide additional insurance that the loads will transfer from the side wall, a mid-point and quarter-point 2 x 12 brace is provided in the upper half of the door unit, and is connected to the stringers, using the metal connectors described earlier. Figure 8 illustrates the construction of the door unit. The door described in the third alternative becomes most practical, even though sandbags are needed to withstand the negative phase. The necessary sandbags could be stored in the excess space in the door unit and should not prove to be inconvenient for the occupants to stack behind the door.

The side or end wall of the lean-to shelter is constructed in a manner that is similar to the construction of the lean-to wall. The 2 x 12 stringers are placed vertically in the triangular opening, and 3/4-inch plywood is applied to both sides of the 2 x 12's. Stringers are attached to the 2 x 12 floor plate using the same metal connectors used elsewhere in the lean-to. The wood floor plate is connected to the concrete floor in the same manner as the longitudinal floor plate. The tops of the vertical stringers should be attached to the end diagonal 2 x 12 member of the door module. This 2 x 12 should be doubled so the lateral impact load can be transmitted to the diaphragm of the plywood stressed-skin panels evenly.

The wood materials used in the construction of the lean-to shelter can readily be purchased at any lumber yard. The wood members should be stress-graded (select-structural) and should be pressure-treated with a fire-retardant chemical. Prevention of the spread of fire is very important to the success of the shelter. During the initial thermal radiation effect, exposed surfaces can be scorched or cause fires, depending upon the combustibility of the material. Therefore, knots, checks, and other defects should be kept to a minimum. The plywood should be exterior-grade A-C, and the "A" surface used as the exposed surface of the lean-to. This will somewhat minimize the combustibility of the material. The adhesive used to glue the members together should be casein, type II or phenol-resorcinol. The manufacturer's directions

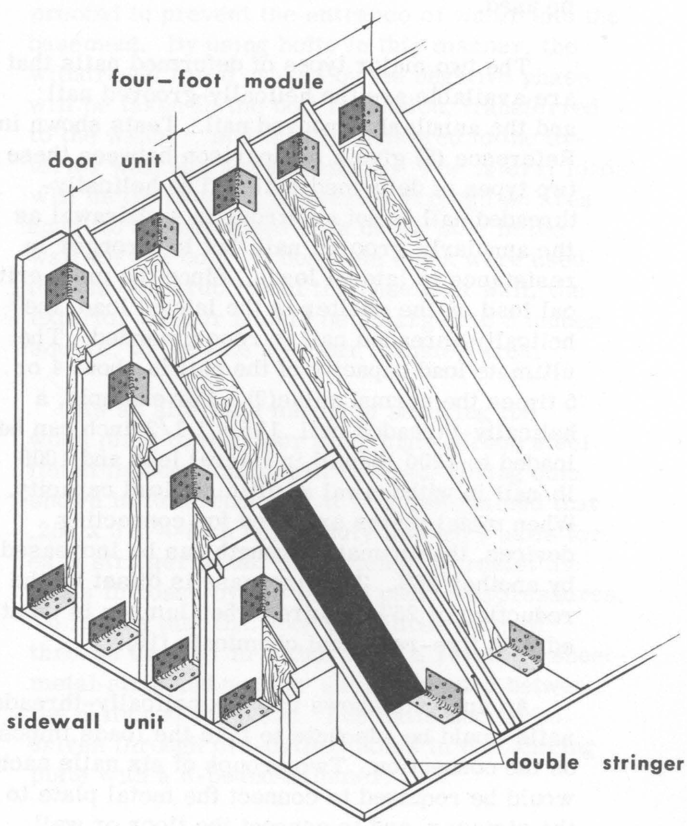


Figure 8

and temperature recommendations should be followed very carefully when using these adhesives, or failure of the glue joint can result.

The helically-threaded nails, the special metal connectors, and the special-size sandbags will not be readily available to the general public. The helically-threaded nails are not generally stocked by local lumber and hardware stores. The metal connectors, as discussed earlier in this report, are a special design and would have to be fabricated for each shelter. If the connectors could be mass-produced, the cost of the connectors could be substantially reduced. The sandbags should be manufactured with a dimension of 14" x 11 1/2" x 5 3/4", since these should fit the space between stringers and the space between the plywood faces. The sandbag, when filled, will weigh approximately 65 to 70 pounds, and could be handled and placed by one or two people.

It is suggested that the shelter accessories can be made up into a kit form, consisting of the empty sandbags, metal connectors, and special nails, and be made available to the general public. These kits could contain all the accessories needed to construct the lean-to shelter.

In addition to the common hand tools, such as hammers, wrenches, and hand saws, the homeowner will also be required to rent or borrow tools such as a rotary impact drill for making the holes to receive the floor bolts and for drilling the holes through the concrete basement walls, and, if powder-actuated fasteners are used, this tool will also have to be rented or borrowed.

The erection procedure used to construct the lean-to is very simple and straight-forward. As much of the unit as possible is prefabricated on the floor of the basement before it is lifted and fastened in the place against the floor and wall.

The interior face of the stressed-skin panel should be nail-glued to the bottom of the stringers, and the wall bearing plate should be fastened with the metal connectors to one end of the stringers. Bolt holes for fastening the module to the basement wall should be pre-drilled through the basement wall and through the wall bearing plate. The unit can then be lifted by two men and placed against the basement wall, lining up the bolt hole. The bolt is then placed from the inside of the basement through the wall bearing plate and basement wall, and the washer and nut placed on the outside of the basement wall. The door unit can be fabricated in a similar manner, and then the end wall, or side wall, can be fabricated to fit the resulting open space. Once the shelter modules and door unit are in place, the voids between the module stringers can be filled with sandbags and the outer skin nail-glued to the tops of the stringers, completing the shelter.

In summary, the lean-to basement shelter offers a very efficient minimum structure which meets the established shelter requirements. Additional consideration should be given to ventilation, fallout protection, and provisioning the shelter. The survival of the shelter occupants may depend more on the availability of fresh air, food water, and medical supplies than on complete protection against blast and limited fallout.

The lean-to shelter provides 57 cubic feet of volume per person, which is somewhat below the 65 cubic feet per person presently recommended by the Office of Civil Defense. Additional ventilation can be provided for the shelter occupants by the removal of the upper sandbags in the door unit or by the provision of a hand-operated blower. The toe of the lean-to shelter provides excellent space for the storage of provisions such as water containers, food supplies, first-aid kits, blankets, radiation meters, battery-operated radios, and tools, such as crow bars for use in leaving the shelter should the building above collapse around the shelter area. Additional supplies could also be stored near the shelter in the adjacent basement area.

RIGID-FRAME SHELTER

The second shelter design incorporates the use of prefabricated rigid frames for the main structural members of the shelter. The rectangular shape increases the habitability features over the lean-to shape, although it still does not provide clearance for the occupants to stand up within the shelter.

As with the lean-to shelter, the rigid frame shelter takes advantage of the economics, light weight, and ease of working with wood members. The shelter is essentially a sub-structure of rigid wood frames, with plywood inner and outer skins and sandbags used as filler material. The elements of the shelter are designed as 48-inch modules, similar to the lean-to shelter, so that standard 4'-0" sheets of plywood can be used (see Figure 9a).

From the space requirements mentioned earlier in this report, the minimum rectangular shelter needed to accommodate three adults could have the dimensions of 4'-0" high by 4'-0" deep by 8'-0" long. This shape would provide adequate floor area but would be somewhat inadequate in volume. Lengthening the shelter to 10'-0" still does not provide enough volume within the structure. Increasing the dimensions of the shelter to 5'-0-" wide by 4'-0" high by 10'-0" long provides sufficient volume within the structure. The following design was based on these dimensions.

The 4'-0" height dimension results in a total height of approximately 5'-0", which still leaves more than 2'-0" of working space above the shelter, even in a shallow basement. This space is needed to place the sandbags and to complete the attachment of the outer skin to the shelter.

Structurally, the rectangular shelter consists of 2 x 12 roof and wall members connected by 1/2-inch plywood gussets, nail-glued at the joint between wall and roof to form a rigid frame. The frames are spaced approximately 16 inches on center and faced on both sides with 3/4-inch plywood stressed-skins. Both wall and roof elements are designed to withstand 10 PSI peak overpressure loadings. The rigid frame design results in a large portion of the bending moment being concentrated at the joint. The two rectangular plywood gusset plates shown in Figure 9a adequately take the loading imposed on the joint. The 23-inch dimension of the gusset plate is somewhat over-designed, but it insures the needed rigidity and eliminates shear failure in the plywood by enlarging the glue area. To provide lateral rigidity between the module units, they are joined at the top and side of the rigid frame by a strip of plywood that has its grain running perpendicular to the frames (see Figure 10).

The stressed-skin design allows the modules to act as a unit, both in compression and in combined bending. Although the skin is subjected to a lateral force from the sidewalls, the section is stiff enough to resist both lateral torsional and buckling effects. Both compression and bending are relatively low, and their combined effect will not cause failure. The governing stress is still shear, but, as in the lean-to structure, using the same cross-sectional design, the shelter will withstand 10 PSI loadings without an internal stress failure.

Also, as in the lean-to design, the most critical joint is the connection to the basement wall and floor. In the rigid-frame shelter, however, the lateral force is more significant because the direct bearing and wedge action cannot be depended upon to carry the load.

The analysis of the blast effect on the rigid-frame structure is similar to that used for the lean-to structure. Since the blast wave is somewhat erratic as it enters the basement, a 10 PSI peak overpressure loading was considered separately on both the roof and wall elements. With the 10 PSI loading on the roof section only, the lateral shear force is most critical. To resist this shear force, eight 1 1/2-inch helically threaded nails are needed to connect the rigid-frame elements to the wall and floor bearing plates through the metal connectors. To anchor the wall bearing plate to the wall, one 1-inch round bolt with a 3 x 12 bearing plate could be

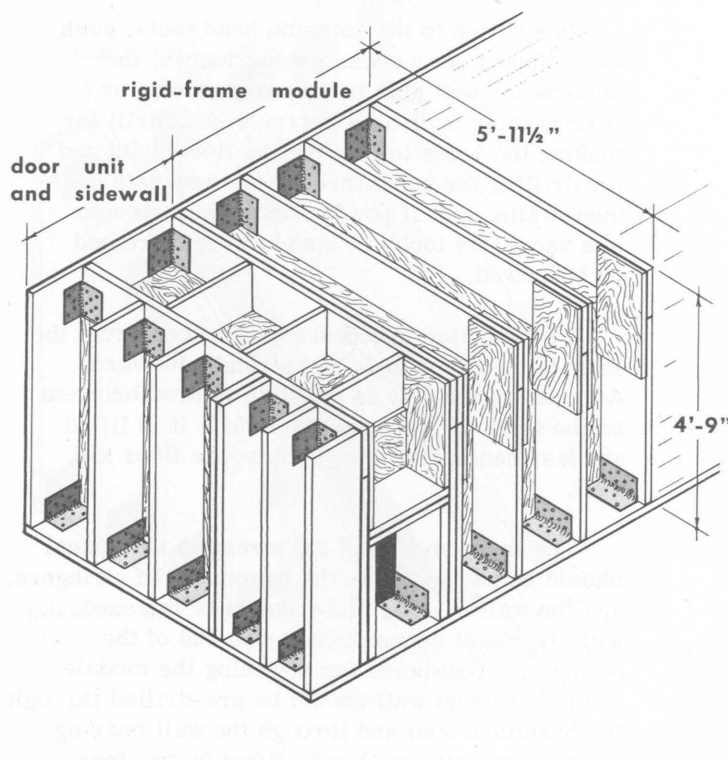
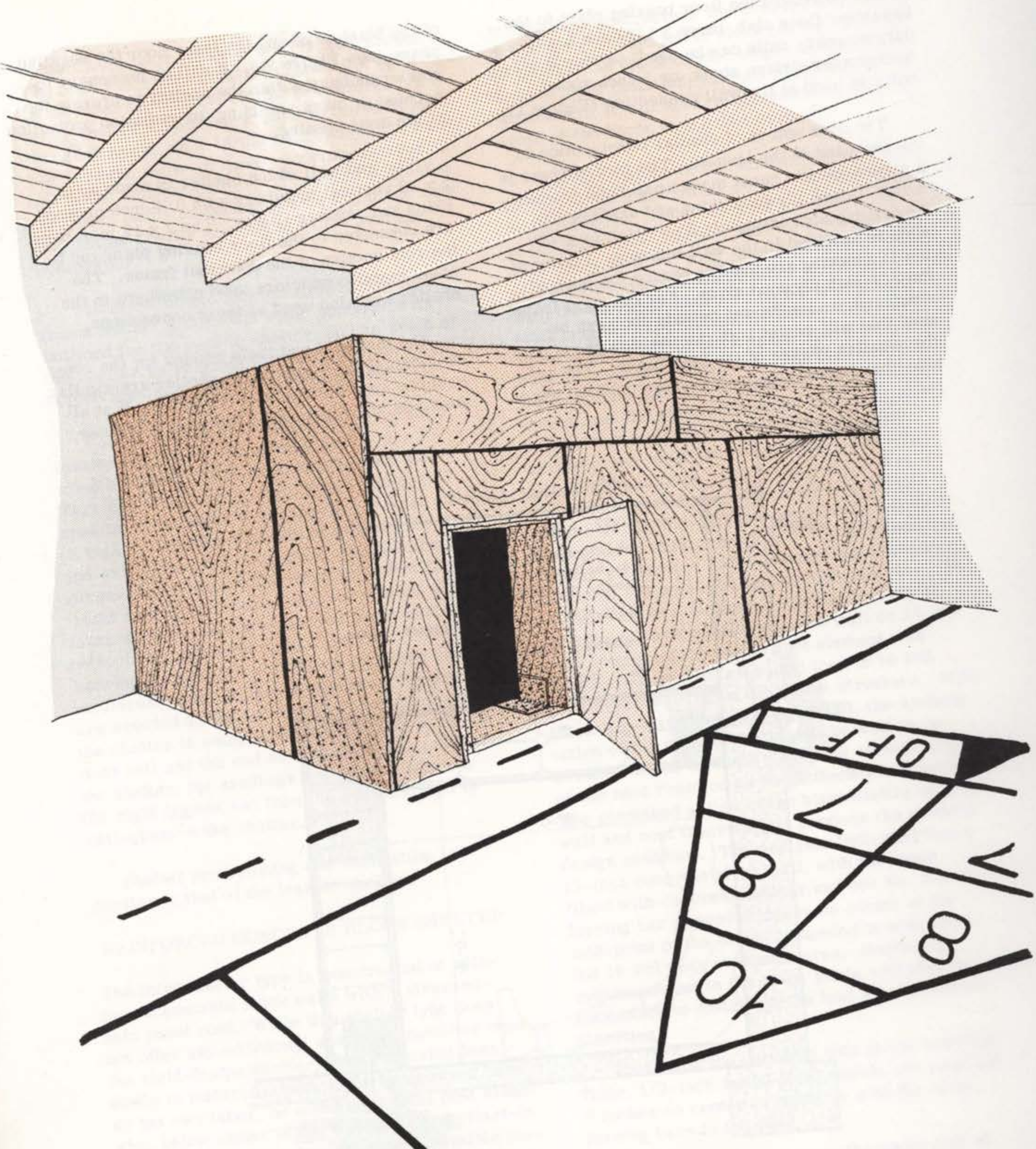


Figure 9



RIGID—FRAME SHELTER

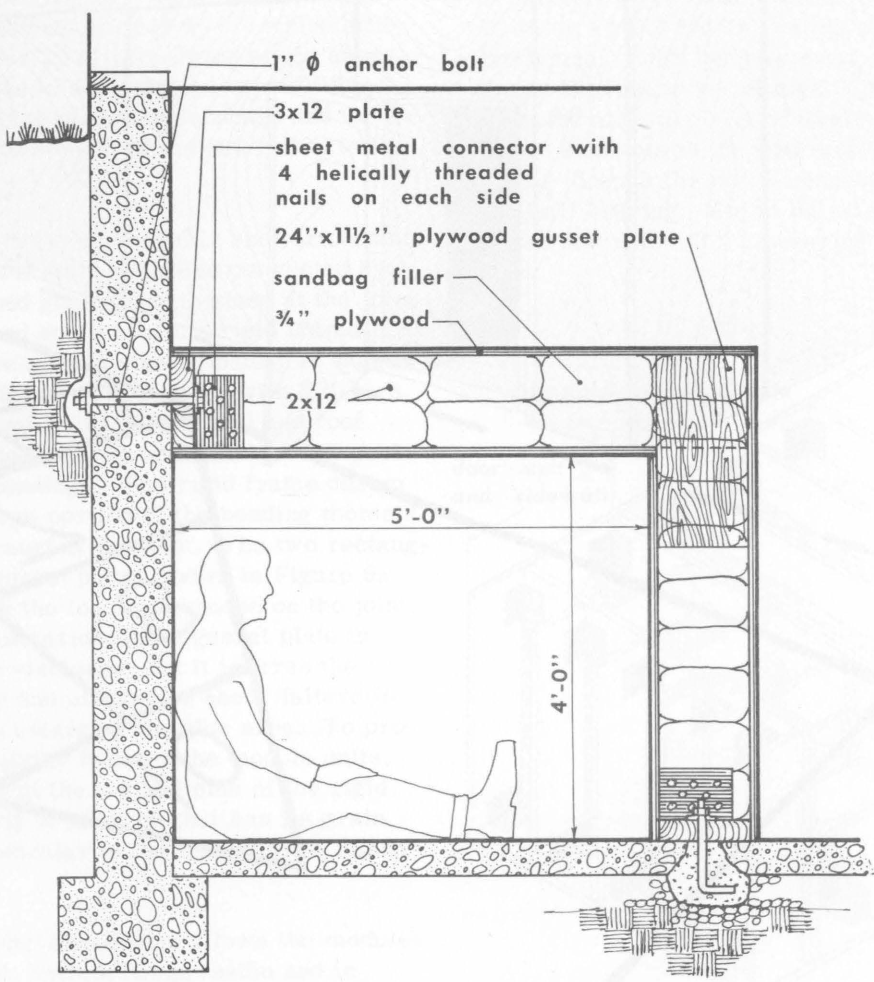
Figure 10

used. To secure the floor bearing plate to the basement floor slab, three 3 1/2-inch heavy-duty masonry nails can be used, or four 3 1/2-inch powder-driven studs, or 1-inch round bolts as used at the wall connection (Figure 11).

The door unit is of similar construction to the one used in the lean-to. The roof element is a stressed-skin panel made up of rigid frames with 3/4-inch plywood skins and sandbag fill. An opening approximately 3'-0" high by 1'-6" wide is provided in the wall element. Pieces of 2 x 12 blocking are used to reduce the span of the 3/4-inch plywood skins. For the rigid frame structure, an inside and outside door can be used that will resist both the positive phase of the negative phases of the blast wave. The outside door is designed to resist the positive phase of the blast wave and the inner door the negative phase (see Figure 9b). It will be necessary to stack sandbags within the shelter to provide the necessary mass shielding for radiation protection at the door opening.

The end wall of the shelter is made up of 2 x 12 vertical members with 3/4-inch plywood skins and sandbag fillers. The 2 x 12 members are connected to the floor bearing plate and to the roof section of the door unit frame. The sheet metal connectors used elsewhere in the shelter are also used at these connections.

The material and tools needed for the construction of the rigid-frame shelter are similar to those used for the lean-to shelter. If at all possible, the plywood for the inner and outer



SECTION : RIGID–FRAME SHELTER

Figure 11

skins should be purchased in 4' by 10 ' sheets. The use of this size plywood sheet will result in the most economical cutting procedure. The other shelter accessories, such as the helically-threaded nails, sheet metal connectors, and sandbags are the same as those recommended for use in the lean-to shelter. It is again suggested that these items be packaged as a kit, since they may not be readily accessible to the average homeowner.

The construction and erection of the rigid frame shelter follows the same procedure as outlined for the lean-to shelter, and as much of the shelter as possible should be prefabricated before the units are erected against the wall.

The first stage of construction consists of fabricating the rigid frames from the 2 x 12 wood members. It is important to note that there are two types of rigid frames in each module. The interior frames have gusset plates on both sides of the connection between the roof and wall elements, while the end frames have gusset plates only on the interior face of the frame (see Figure 9a). After the frames are fabricated, the interior plywood skins should be applied to form the 4-foot module. The wall bearing plate and floor bearing plate are anchored as discussed in the lean-to shelter. The modules are erected as the fabrication takes place, and the shelter is completed by the assembly of the door unit and the end or side wall. To complete the shelter, the sandbags are placed between the rigid frames and then the exterior skin is nail-glued to the shelter.

Shelter provisioning and ventilation is similar to that of the lean-to shelter.

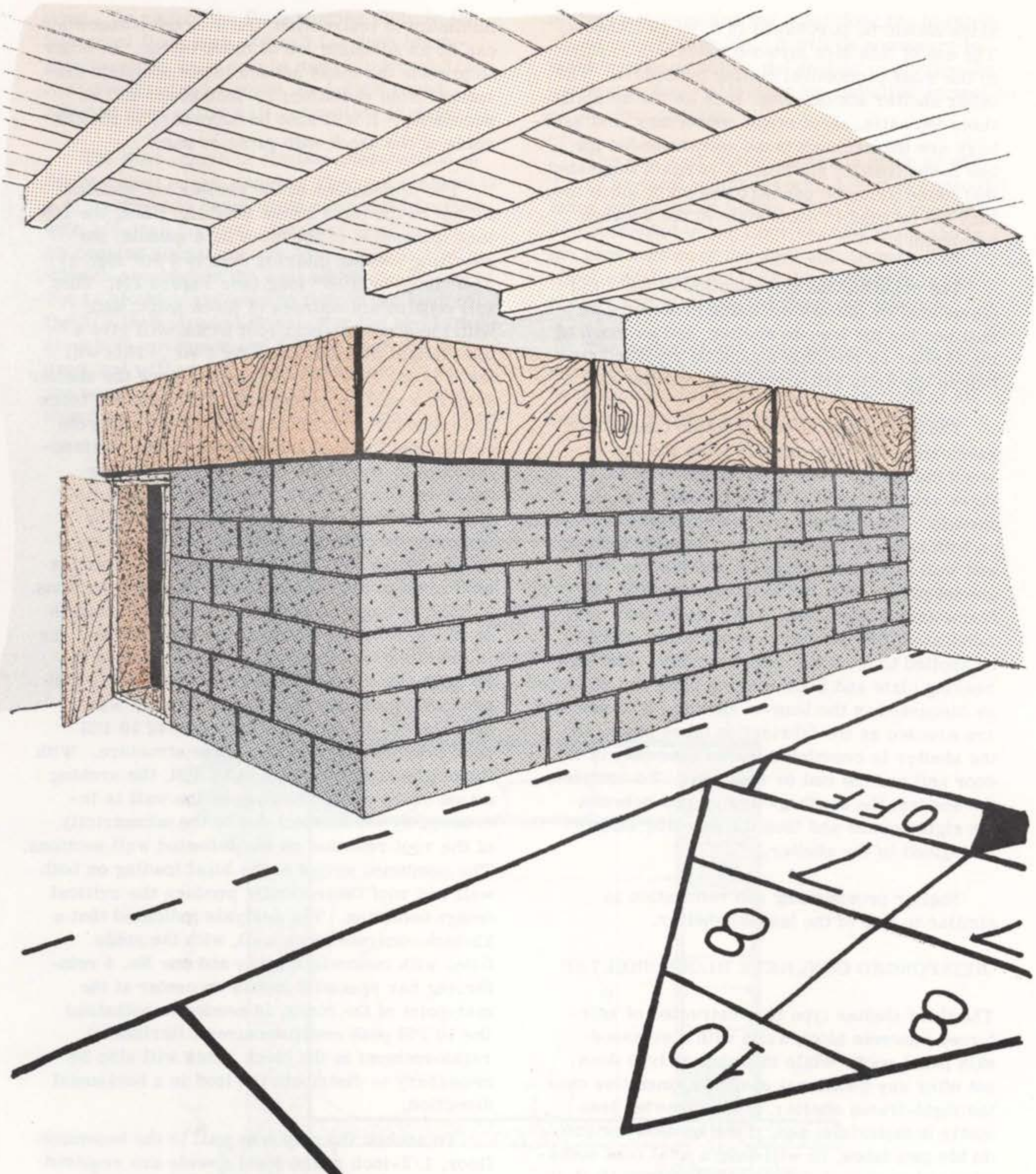
REINFORCED CONCRETE BLOCK SHELTER

The third shelter type is constructed of reinforced concrete block walls with a stressed-skin panel roof. While this shelter type does not offer any additional space or amenities over the rigid-frame shelter, it is somewhat less costly in materials, and, if the homeowner can do his own labor, he will have a total cost somewhat below either of the wood shelters. Cast-in place concrete was eliminated as a possible material for the construction of the shelter because of the expense of formwork and labor, and the difficulty in handling for the average homeowner. However, concrete blocks are relatively light in weight, require no formwork, and, with a minimum of instruction, the average homeowner can do an adequate job of block laying. In order to provide the mass needed to get adequate protection from radiation, 12-inch block will be necessary. It will also be necessary to fill the voids of the block with grout or sand.

The dimensions of the shelter are similar to that of the rigid frame shelter. Using the 16-inch dimension of the block as a module, the resulting shelter interior size is 4'-0" high by 5'-0" deep by 9'-8" long (see Figure 12). This will require six courses of block work, and, with the stressed-skin roof panel, will give a total height of approximately 5'-0". This will leave about 2'-0" of work space above the shelter even in a shallow basement. The concrete block wall depends upon the strength of the concrete mortar and the size and spacing of the reinforcing bars to resist the blast loading. In this analysis, the wall was considered to span its full height and to be simply supported. The wall was then designed for an arching action failure at the mid-height mortar joint, which is analogous to plastic bending of masonry sections. Mortar strength of 2,000 PSI and steel strength of 40,000 PSI was assumed for the analysis. As in the other two shelters, a partial loading of 10 PSI peak overpressure on the wall or 10 PSI peak overpressure on the roof element was considered, as well as a total load of 10 PSI peak overpressure on the entire structure. With the entire structure load at 10 PSI, the arching action of the plastic bending of the wall is increased by the moment due to the eccentricity of the roof reaction on the deflected wall sections. The combined action of the blast loading on both wall and roof theoretically produce the critical design condition. The analysis indicated that a 12-inch concrete block wall, with the voids filled with concrete mortar and one No. 4 reinforcing bar spaced 8 inches on center at the mid-point of the block, is needed to withstand the 10 PSI peak overpressures. Horizontal reinforcement in the block joints will also be necessary to distribute the load in a horizontal direction.

To anchor the concrete wall to the basement floor, 1/2-inch round steel dowels are required 8 inches on center to coincide with the reinforcing bars in the wall.

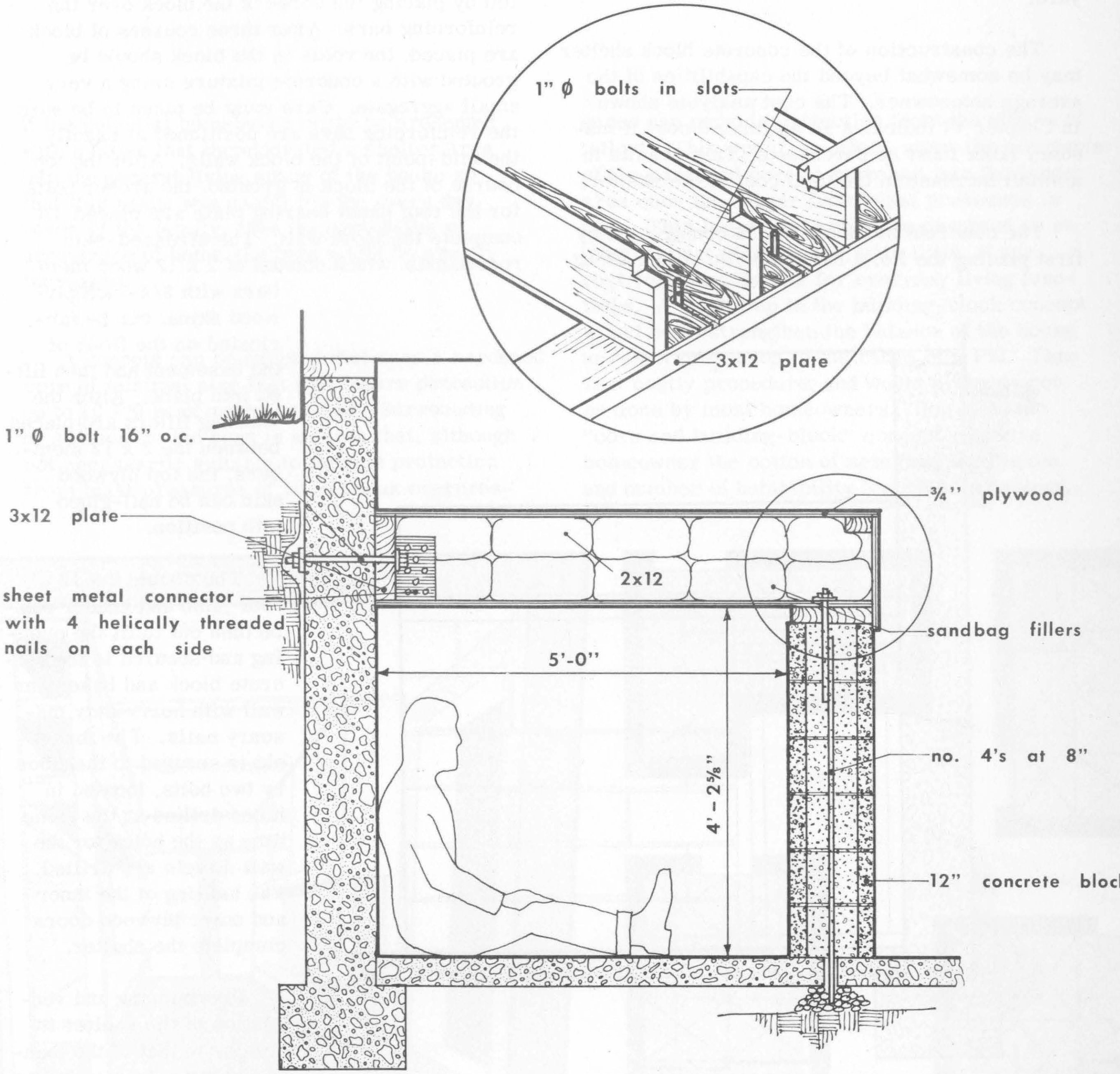
The shear reaction from the upper half of the wall is transferred through the stressed-skin roof panel in diaphragm action. The roof-wall connection is designed to resist this lateral



REINFORCED CONCRETE BLOCK SHELTER

Figure 12

load. As shown in Figure 13, the connection is somewhat different than the wall and floor connection shown for the lean-to and rigid-frame shelters. Instead of using the sheet metal connectors, the shear is transferred directly from the bearing plate into the lower skin of the roof panel. It uses 3/4-inch round bolts, anchored in the voids of the block and spaced 16 inches on center between each roof stringer, to transfer the wall shear to the 2 x 12 bearing plate. The lateral load is then transmitted through the roof panel to the basement wall. The roof panel is secured to the basement wall in the same manner as used for the rigid-frame shelter.



SECTION : REINFORCED CONCRETE BLOCK SHELTER

Figure 13

The door of the shelter is located in the end or side wall. A double 2 x 10 member forms a jamb and provides a door opening 17 1/2" wide and 48" high. An inner and outer plywood door complete the end wall (see Figure 14).

The materials needed to build the concrete block shelter are readily available. Concrete block, reinforcing bars, and pre-mixed cement mortar can be purchased at any material supply yard.

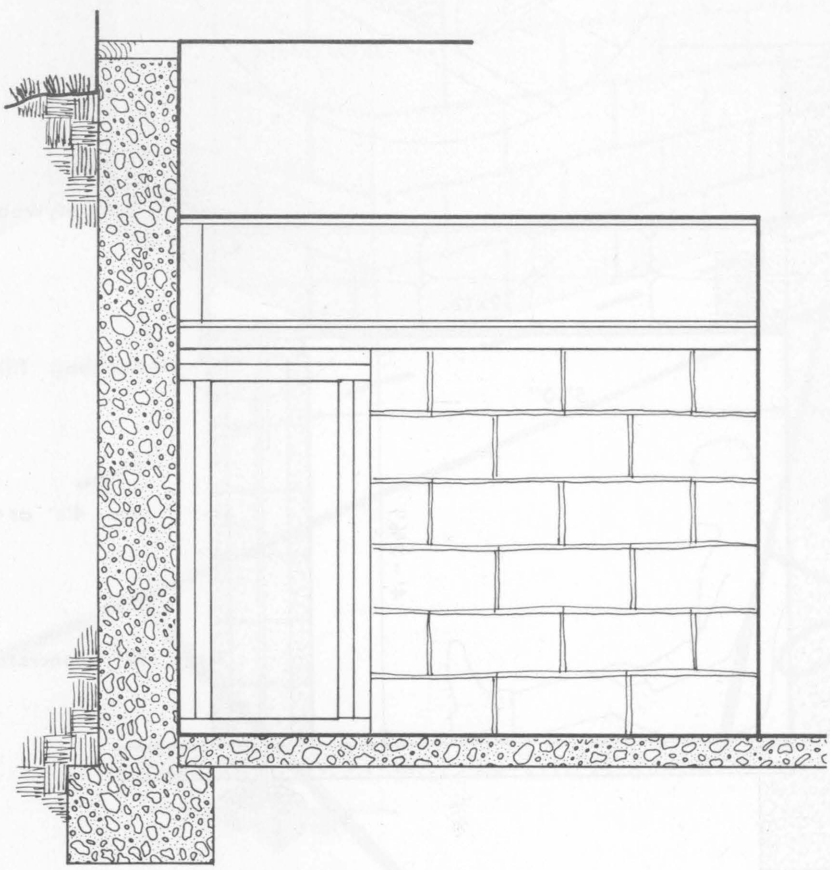
The construction of the concrete block shelter may be somewhat beyond the capabilities of the average homeowner. The cost analysis shown in Chapter VI indicates an estimated cost if masonry labor must be purchased. This results in a small increase in the total cost of the shelter.

The concrete block shelter is constructed by first placing the No. 4 bars at 8" on center along the location of the walls. Since the wall is only 4'-0" high, it is simpler to place the bars rather than use a combination of dowels and bars. If the shelter is being built in an existing basement, holes will have to be drilled into the floor slab at the dowel locations. Hooking the dowels will not be necessary since the withdrawal force is quite small.

The concrete block walls are then constructed by placing the cores of the block over the reinforcing bars. After three courses of block are placed, the voids in the block should be grouted with a concrete mixture using a very small aggregate. Care must be taken to be sure the reinforcing bars are positioned at exactly the mid-point of the block walls. After the top course of the block is grouted, the anchor bolts for the roof panel bearing plate are placed, to complete the block wall. The stressed-skin roof panels, which consist of 2 x 12 wood members with 3/4-inch plywood skins, can be fabricated on the floor of the basement and then lifted into place. After the sandbag fillers are placed between the 2 x 12 members, the top plywood skin can be nail-glued into position.

The double 2 x 12 door jamb and header can be then cut to fit the opening and secured to the concrete block and basement wall with heavy-duty masonry nails. The threshold is secured to the floor by two bolts, located in holes drilled at the same time as the holes for the wall dowels are drilled. The hanging of the inner and outer plywood doors complete the shelter.

Provisioning and ventilation of the shelter is similar to that of the lean-to and rigid-frame shelter.



SIDEWALL ELEVATION OF CONCRETE BLOCK SHELTER

Figure 14

V. Core and Building Block Concept

If the potential homebuyer could be presented with a house that incorporated a shelter area into the general living space of the house so that this space was useful for the every day needs of the family, then the probability of acceptance of home shelters might be greatly increased.

A concept can be adopted that uses a hardened core of minimal size that will insure protection up to 10 PSI peak overpressures. Surrounding or adjacent to the core is an area that, although not necessarily suitable to provide protection from blast pressures of 10 PSI peak overpressures can provide protection from the effects of fallout. This would, in effect, allow the occupants of the hardened core to move out into the larger area once the danger from blast pressures is past. This larger area must be designed as an integral part of the house, with little, if any, restriction on its use for everyday living functions. A final step in the building-block concept would be to strengthen the balance of the house to resist pressures in the range of 5 PSI. This is a costly procedure, and would probably not be done by most homeowners. However, the "core and building-block" concept gives the homeowner the option of selecting the degree and number of habitability features he desires.

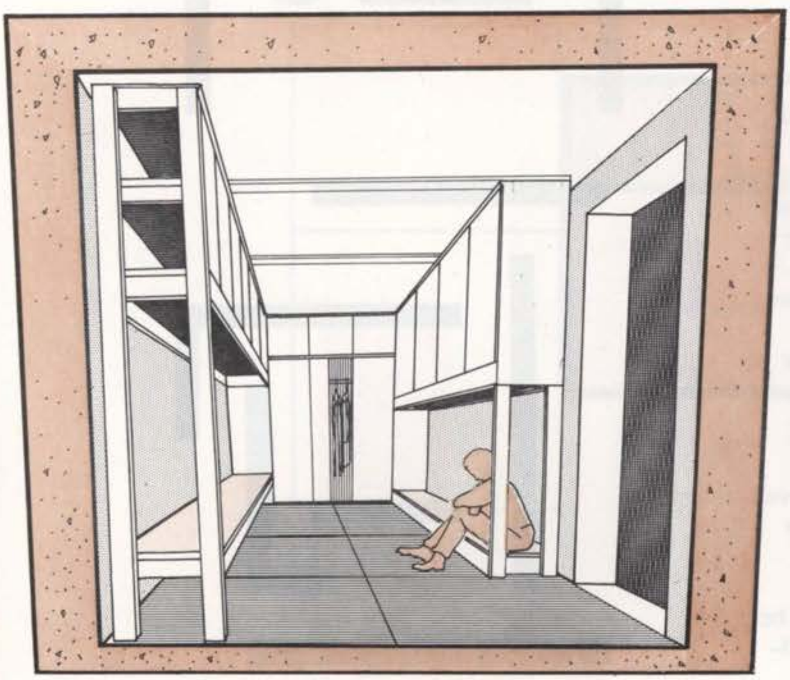


Figure 15 Six Person Blast Core

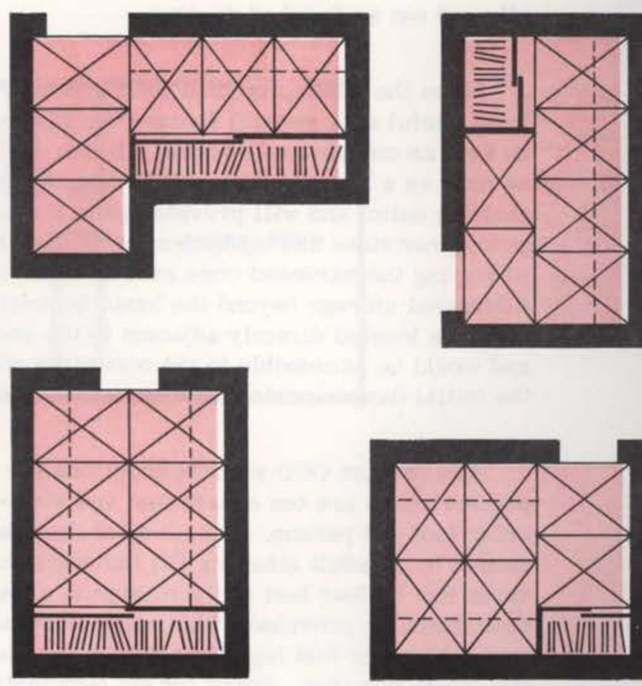


Figure 16 Blast Core Variations

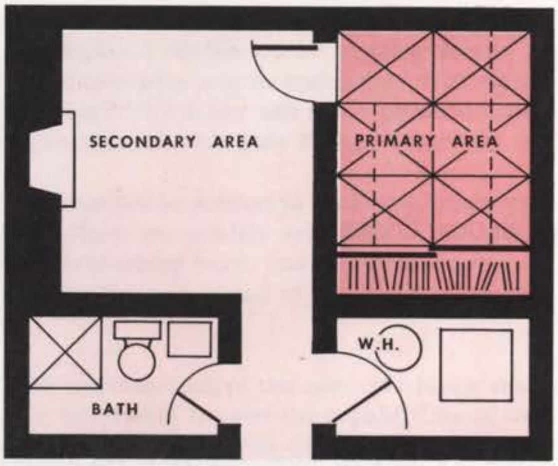


Figure 17 Core and Secondary Areas

To illustrate this concept, a number of architectural studies have been prepared, using typical "builder-oriented" designs as a base and then modifying the basic schemes. The use of this concept requires that the shelter areas given consideration during the design stages of the house. It is not a feature that can be easily added after the house is completed. The actual structural design or wall masses are not given in this discussion, since the studies are presented as examples of what can be done architecturally and not as finished designs.

Since the blast-protected area will be the least useful as a general living area, it should be kept as compact as possible. It can still be used as a storage area, with properly designed shelving units; and will provide space for emergency provisions and equipment necessary for occupying the hardened core area (Figure 15). Additional storage beyond the basic necessities could be located directly adjacent to the core and would be accessible to the occupants after the initial danger period is over.

The present OCD recommendations for shelter space are ten square feet and sixty-five cubic feet per person. The study of the space needed by an adult (chapter IV) indicates that three feet by four feet is the minimum area that should be provided. This space need not be more than four feet high if provision for standing is not required. Space for six occupants can be arranged in a number of fasions. Some of the possible variations are shown in Figure 16.

Taking a six-person core arrangement, the secondary or fallout-only area can be added as shown in Figure 17. The secondary area shown in the illustration incorporates the water heater (as a possible water storage source), a bathroom (should community utility services be available), and a fireplace for heating and cooking use.

The illustration indicates solid walls en-

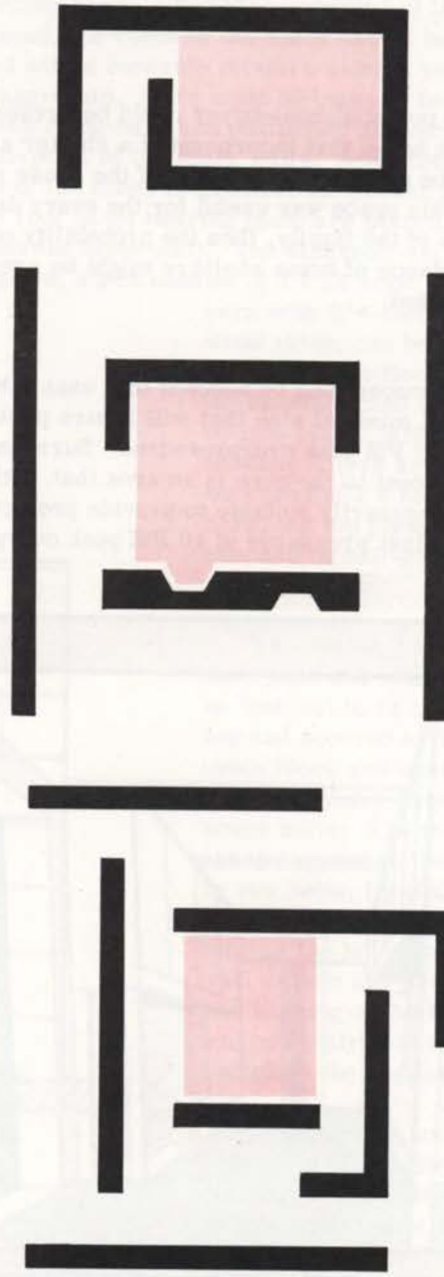


Figure 18 Baffles in Plan

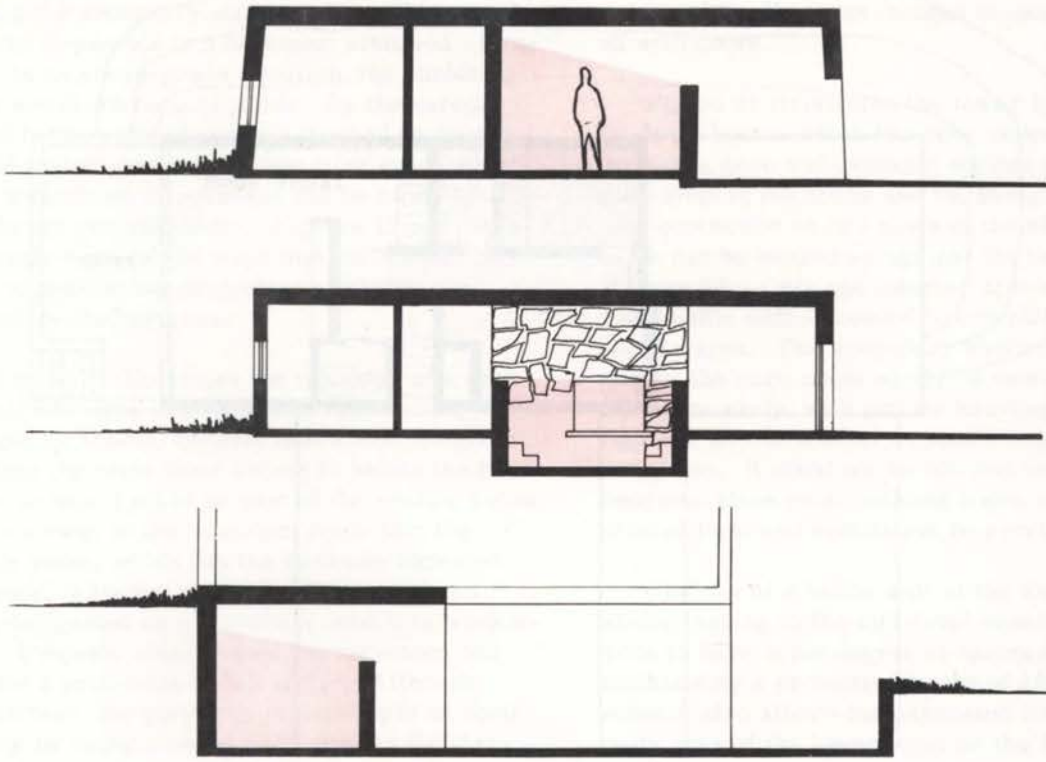


Figure 19 Baffles in Section

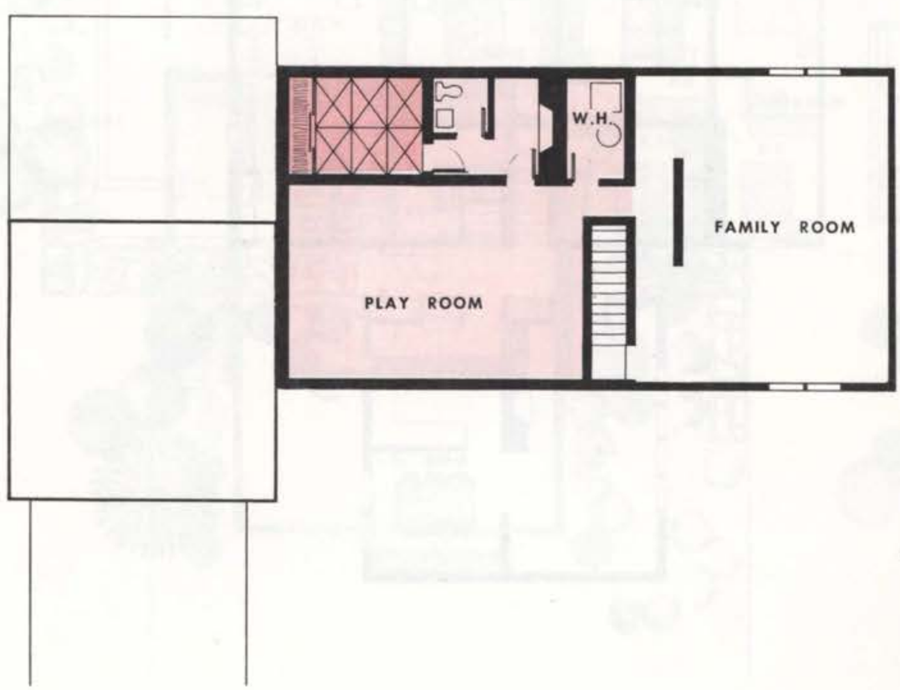


Figure 20 Basement Shelter

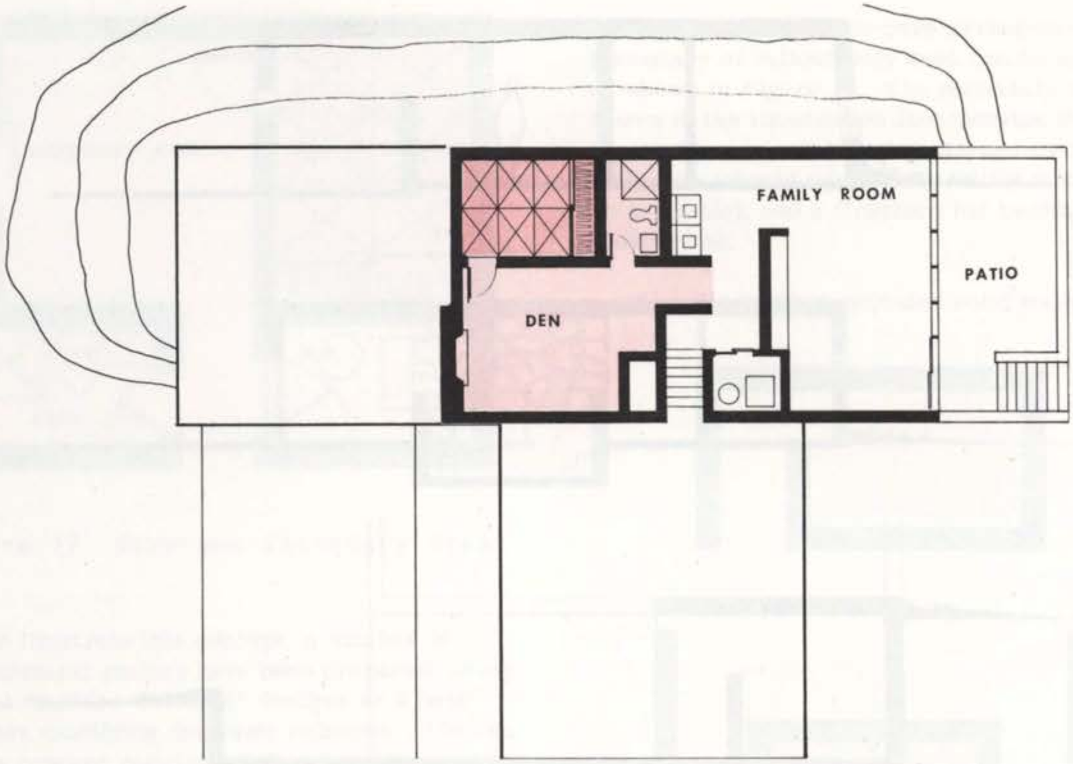


Figure 21 Lower Level

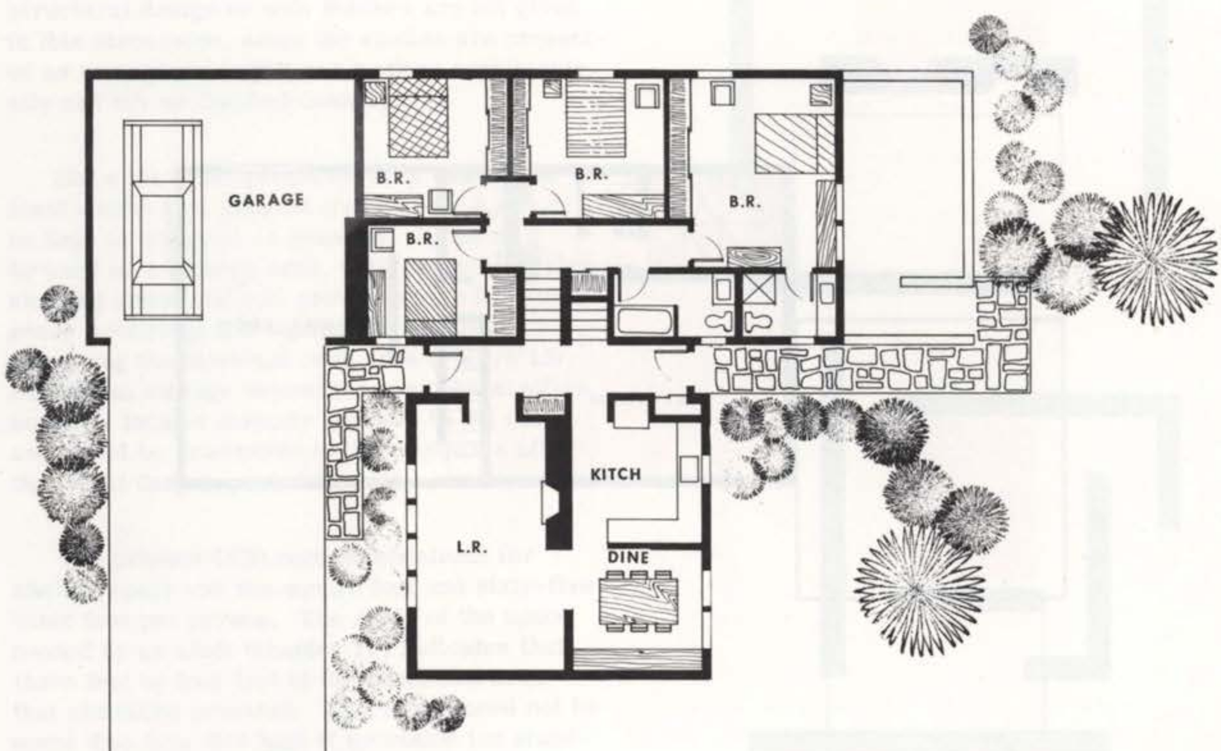


Figure 22 Upper Level

closing the secondary shelter area. This would be easy to provide in a basement situation. However, in an above-grade situation, the enclosing walls would not be acceptable. By the careful use of baffle walls, the same level of protection can be maintained and the resulting space can have some level of openness and be more acceptable to the general public. Figures 18 and 19 illustrate some of the ways that baffles can be used to provide the protection needed in the secondary shelter area.

Figure 20 illustrates the inclusion of a core and shelter area in a basement application. No changes or special consideration was needed in planning the main floor except to locate the fireplace so that it could be part of the shelter below. The stairway to the basement feeds into the family room, which has the normally expected windows. Adjacent to the family room is an area designated as a playroom, which is windowless. Properly constructed, the playroom can provide a protection factor of 150. Although windowless, the playroom can maintain an open feeling by using a baffle wall between the playroom and family room instead of closing it off with doors.

Figure 21 illustrates the lower level of a tri-level house, which has been redesigned to provide a core and extended shelter area. The mid-level of the house and the garage wing provide protection on two sides of the shelter, and earth can be banked up against the third wall (Figure 22). Only one interior masonry wall and a baffle wall is needed to complete the shelter area. The secondary shelter area outside of the core could easily be used as a den, office, or study, with proper handling of artificial lighting, so that almost no space is lost for daily living use. It could not be counted as a possible bedroom since most building codes require that natural light and ventilation be provided.

The use of a baffle wall at the foot of the stairs leading to the mid-level enables the shelter area to have some degree of openness while still maintaining a protection factor of 100. This scheme also allows for expansion into the family room area of the lower level as the intensity of

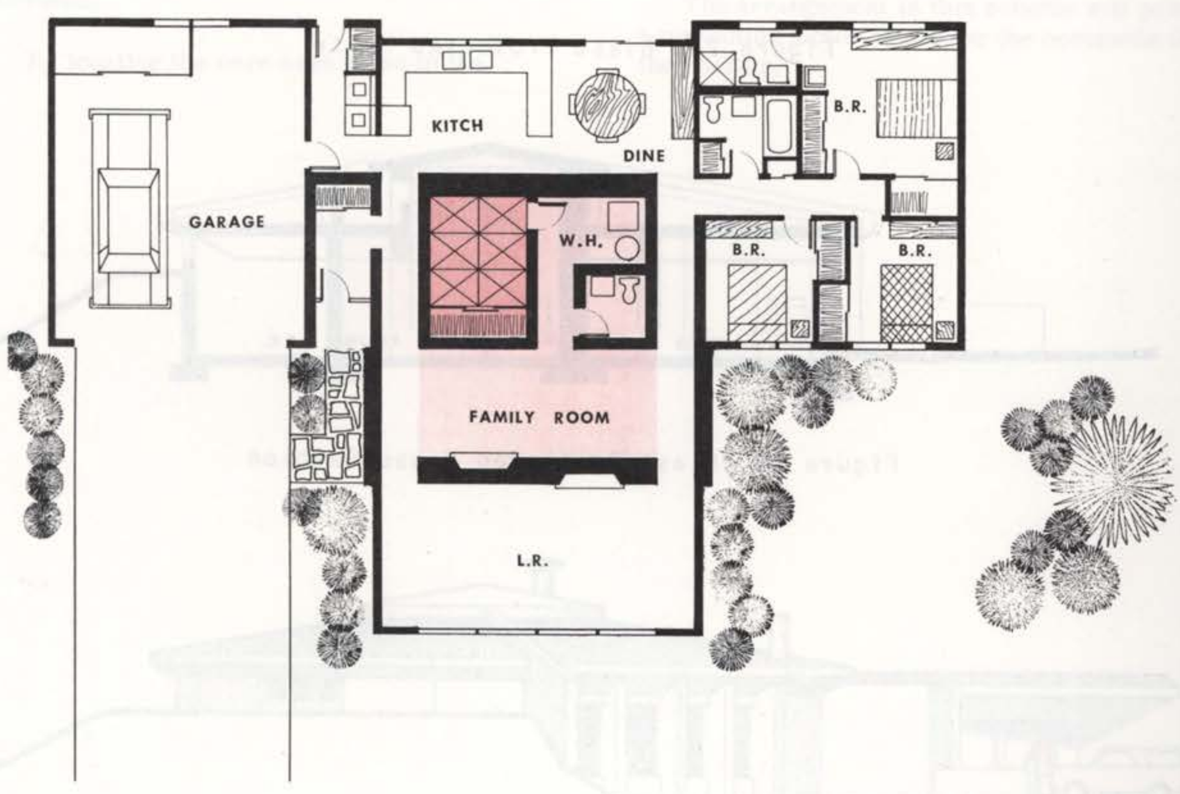


Figure 23 Above-Ground Shelter

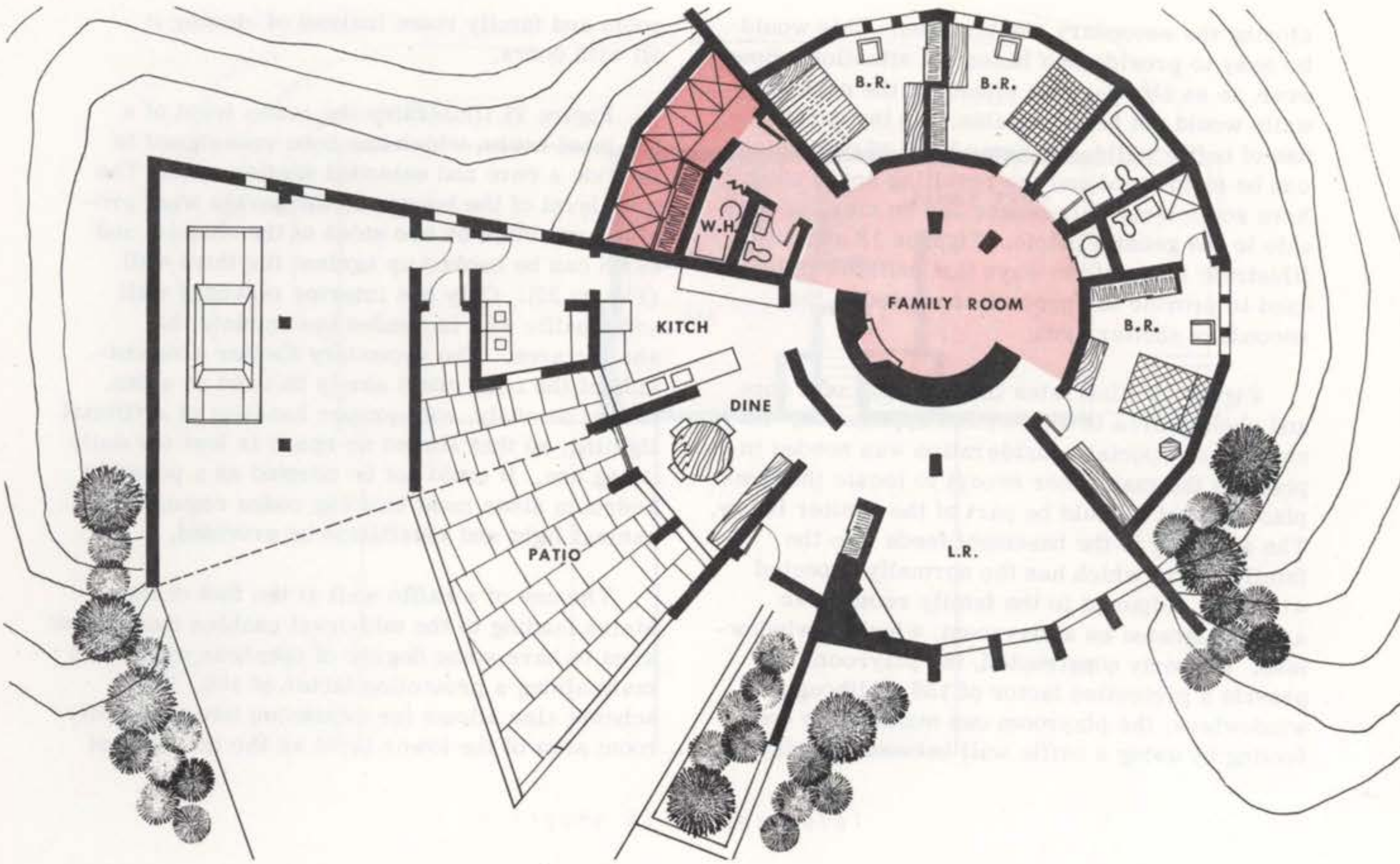


Figure 24 Blast Protected House

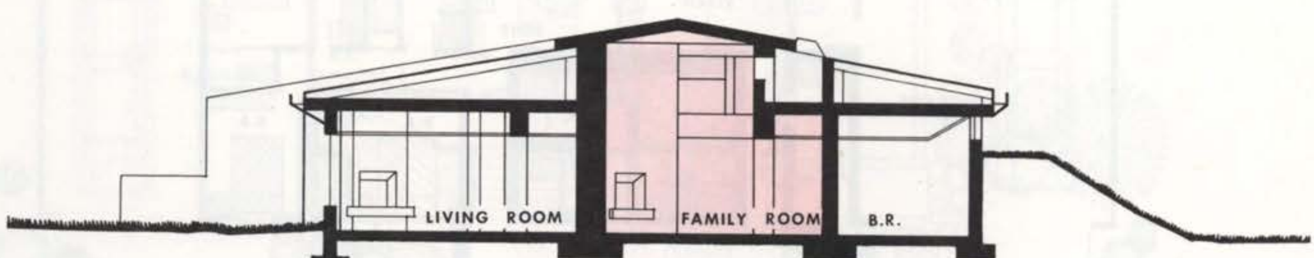


Figure 25 Blast Protected House-Section

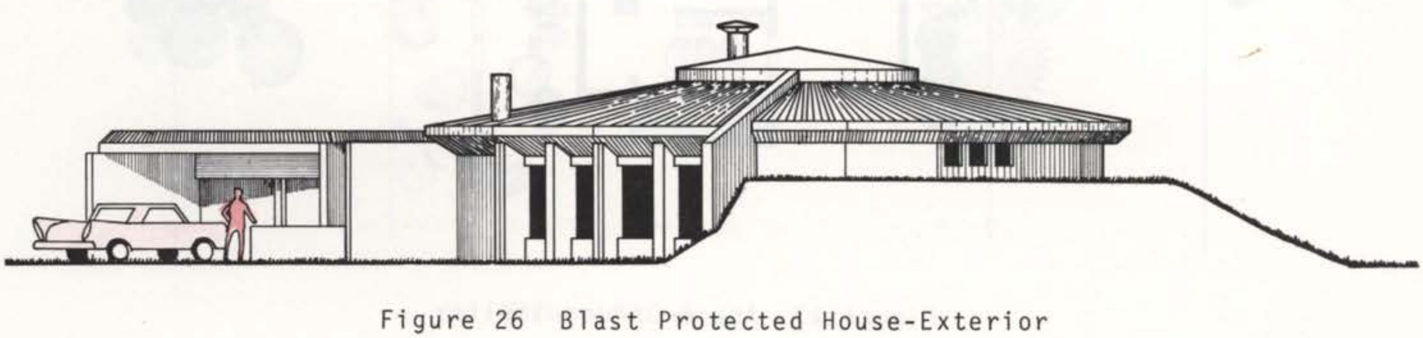


Figure 26 Blast Protected House-Exterior

the fallout decreases and/or if the patio area outside the family room can be decontaminated by washing down.

The arrangement discussed here presents an almost ideal solution, since it solves the problem of the area where deep basements are not possible because of water, rock, or other subsoil conditions while providing the core and shelter area with a minimum of rearrangement of the basic house scheme.

There are areas of the country where, because of special founda'ion conditions, any excavation below grade is impossible, so that even the minimum amount of excavation needed in the previous example is not feasible. In these areas, shelter must be provided above grade--a much more difficult and expensive problem to solve.

Figure 23 illustrates one solution to the above ground shelter and core area that makes maximum use of the shelter area for everyday living requirements. The heavy fireplace wall and the masonry walls without openings adjacent to the area will give a protection factor of 100 if a 10 1/2-inch concrete slab is provided overhead.

By locating the core area close to the center of the house, advantage is taken of the geometric shielding offered by the rest of the house. Even if the rest of the house is destroyed by the blast pressures, the construction used in the core and shelter area will remain standing and provide shelter for the inhabitants.

Figure 24 illustrates another technique for providing blast and fallout protection when excavation is impractical or impossible. The entire structure in this example is strengthened to resist overpressures up to 10 PSI. The house is planned around the core and shelter area. A circular plan is used so that the maximum amount of space can be enclosed using a minimum amount of perimeter wall. Mass shielding is provided by locating the core and shelter in the center of the house, by banking earth around half the house (see Figures 25 and 26), and by placing heavy interior masonry walls so that they act as baffle walls for the shelter areas. The large glass areas of the dining, kitchen, and utility rooms face onto a paved court that can be decontaminated to reduce the radiation hazard. The interior family room and bedrooms receive natural light by using baffled clerestory windows and skylights.

The arrangement in this scheme will provide a protection factor of 100 for the occupants of the shelter.

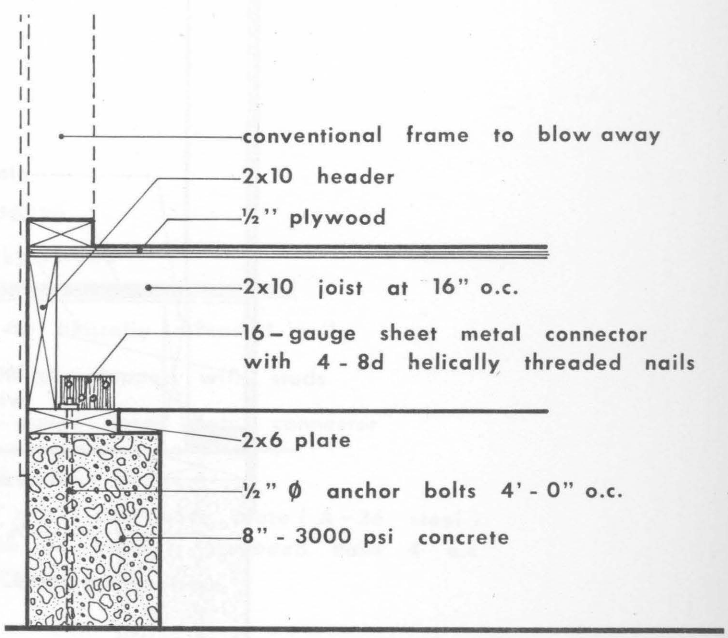
VI. Wood Frame Structures

It is possible that the homeowner may elect to provide additional strengthening in the frame of the house in addition to providing an austere shelter, as discussed in Chapter IV, or even if the more elaborate shelters as shown in Chapter V are used. The additional features may attempt to preserve all or part of the house.

An analysis of a standard balloon-framed house structure indicates that the wall system is the weakest element of the structure. A wall framed with 2 x 4 studs at 16 inches on center, sheathed with 1/2-inch plywood, will resist a peak overpressure of 0.34 PSI. In contrast, the floor system will resist 3.46 PSI and the ceiling system 1.64 PSI when 2 x 10 floor joists and 2 x 6 ceiling joists are used. If the wall sheathing is glued to the studs instead of just nailed, the wall strength can be increased to resist 1.6 PSI, which approaches a more balanced design. (The stud material would have to be stress-graded lumber to achieve this.) Anchorage to the foundation would require 1/2-inch bolts spaced 4'-0" on center (see Figure 28).

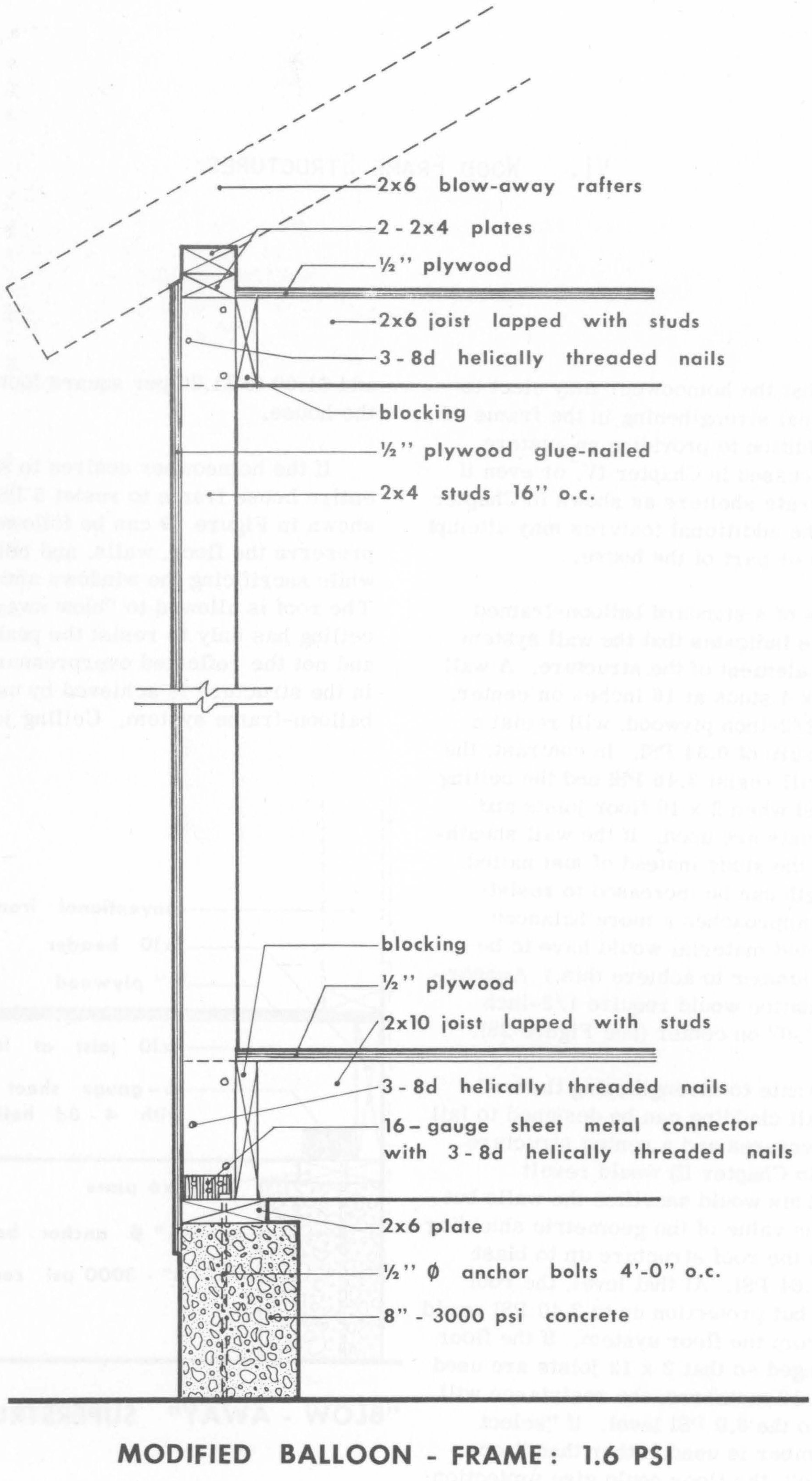
As an alternate to strengthening the wall system, the wall cladding can be designed to fail at very low pressures and a vented structure (as discussed in Chapter II) would result (Figure 27). This would sacrifice the walls but would retain the value of the geometric shielding available from the roof structure up to blast pressures of 1.64 PSI. At that level, the roof would be lost, but protection up to 3.40 PSI would be available from the floor system. If the floor system is changed so that 2 x 12 joists are used in place of 2 x 10 members, the resistance will be increased to the 6.0 PSI level. If "select structural" lumber is used rather than "construction grade", the floor could give protection up to 8 PSI. These minimum improvements to the strength of the house frame will probably add \$1.00 to \$1.20 per square foot to the cost of the house.

If the homeowner desires to strengthen the entire house frame to resist 5 PSI, the details shown in Figure 29 can be followed. This would preserve the floor, walls, and ceiling systems, while sacrificing the windows and roof system. The roof is allowed to "blow away" so that the ceiling has only to resist the peak overpressure and not the reflected overpressure. Continuity in the structure is achieved by using a modified balloon-frame system. Ceiling joists have been



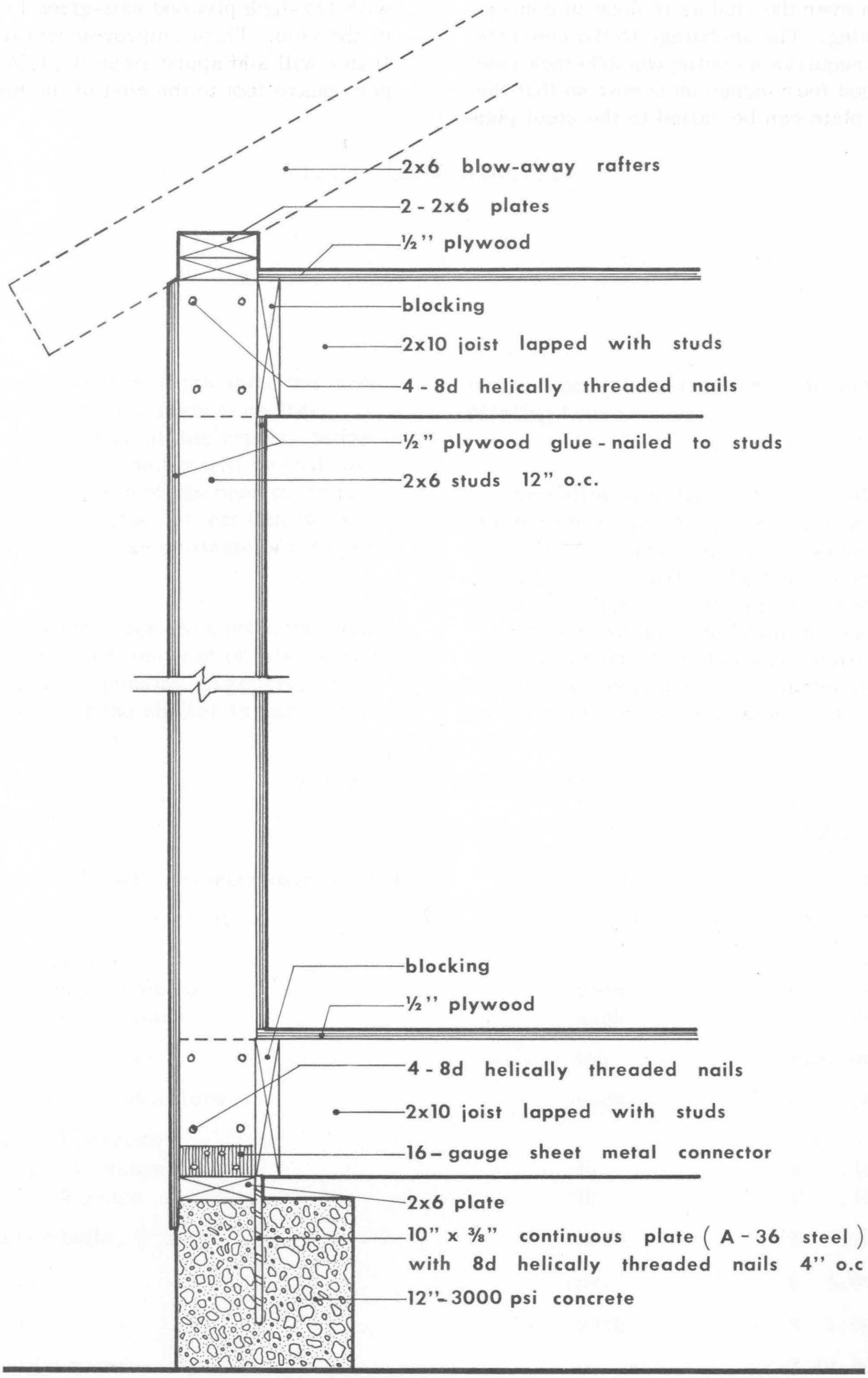
"BLOW - AWAY" SUPERSTRUCTURE: 3.4 PSI

Figure 27



MODIFIED BALLOON - FRAME: 1.6 PSI

Figure 28



STRENGTHENED BALLOON - FRAME : 5 PSI

Figure 29

increased to 2 x 10's and framed into the stud rather than over the stud as is done in conventional framing. The anchorage to the concrete foundation requires a continuous 3/8-inch steel plate punched four inches on center so that the 2 x 6 wood plate can be nailed to the steel plate. The wall studs have been increased to 2 x 6's, with 1/2-inch plywood nail-glued to both sides of the stud. These improvements to the house frame will add approximately $1.80 to $2.00 per square foot to the cost of the house.

VII. Cost Analysis

The tables in this section summarize the material cost for the three minimum shelters discussed in Chapter IV of this report. Since it is assumed that the shelter will be built by the homeowner, no attempt has been made to estimate the cost of labor, except that in the concrete block shelter an estimate of mason's labor has been made.

Should the homeowner elect not to construct the shelter by himself, the cost of labor would vary considerably depending on geographic location and whether the shelter is part of the original house construction or is added to an existing house.

An estimate of the cost of providing the shelter shown in Chapter V is a much more difficult task. The shelter and expansion areas are an integral part of the house construction and it is difficult to differentiate between the "improvement" and the "conventional". An estimated cost of the hardened core is presented in Table V, including an estimated cost per square foot for the expansion area.

TABLE I
ASSUMED MATERIAL COSTS

ITEM	UNIT	COST
Plywood-$\frac{3}{4}$-inch, fire-retardant treated	sq. ft.	\$ .37
Lumber, fire retardant	1000 board feet	\$300.00
Concrete block		
12-inch, grouted	each	\$ .57
8-inch, grouted	each	\$ .38
Reinforcing bars	ton	\$192.00
Sheet-metal connectors	each	\$ .30
Special fasteners		
$1\frac{1}{2}$", 10 gauge	lb.	\$ .40
2", 9 gauge	lb.	\$ .40
Anchor bolts, $\frac{3}{4}$" x 16"	each	\$ .70
Hinges	pr.	\$ 4.60
Latch	each	\$ 1.00
Sand (in bags)	cu. yd.	\$ 14.00
Glue	lb.	\$ 1.00
Concrete		
slabs	cu. yd.	\$ 71.00
walls	cu. yd.	\$ 65.00

TABLE II
LEAN-TO SHELTER MATERIAL COST ANALYSIS

ITEM	UNIT	QUANTITY	UNIT COST	COST
$\frac{3}{4}$-inch plywood	sq. ft.	233	$ .37	$ 89.21
2 x 12 lumber	bd. ft.	358	$ .30	$107.40
Sheet-metal connectors	each	44	$ .30	$ 13.20
Fasteners	lb.	10	$ .40	$ 4.00
Anchor bolts	each	20	$ .70	$ 14.00
Hinges	pr.	1	$ 4.60	$ 4.60
Latch	each	1	$ 1.00	$ 1.00
Sand (in bags)	cu. yds.	4	$14.00	$ 56.00
Glue	lb.	1	$ 1.00	$ 1.00
			TOTAL MATERIAL:	$290.41

TABLE III
RIGID-FRAME SHELTER COST ANALYSIS

ITEM	UNIT	QUANTITY	UNIT COST	COST
$\frac{3}{4}$-inch plywood	sq. ft.	284	$ .37	$105.08
2 x 12 lumber	bd. ft.	320	$ .30	$ 96.00
Sheet-metal connectors	each	50	$ .30	$ 15.00
Fasteners	lb.	12	$ .40	$ 4.80
Anchor bolts	each	24	$ .70	$ 16.80
Hinges	pr.	2	$ 4.60	$ 9.20
Latch	each	2	$ 1.00	$ 2.00
Sand (in bags)	cu. yd.	5.25	$14.00	$ 73.50
Glue	lb.	1	$ 1.00	$ 1.00
			TOTAL MATERIAL:	$323.38

TABLE IV
CONCRETE BLOCK SHELTER COST ANALYSIS

ITEM	UNIT	QUANTITY	UNIT COST	COST
$\frac{3}{4}$-inch plywood	sq. ft.	160	$ .37	$ 59.20
2 x 12 lumber	bd. ft.	222	$ .30	$ 66.60
Sheet-metal connectors	each	16	$ .30	$ 4.80
Fasteners	lb.	7	$ .40	$ 2.80
Anchor bolts	each	16	$ .70	$ 11.20
Concrete block 12-inch	each	66	$ .57	$ 37.62
Reinforcing bars-#4	ton	.03	$192.00	$ 5.63
Hinges	pr.	1	$ 4.60	$ 4.60
Latch	each	1	$ 1.00	$ 1.00
Sand (in bags)	cu. yd.	3	$ 14.00	$ 42.00
			TOTAL MATERIAL:	$235.45
Masonry labor (if needed) 12-inch block	each	66	$ .77	$ 50.82
			TOTAL WITH PARTIAL LABOR:	$286.27

TABLE V
CORE AND EXPANDED AREA

CORE	UNIT	QUANTITY	UNIT COST	COST
Walls:	cu. yd.	12.5	$ 65	$ 809
Roof:	cu. yd.	3.7	$ 71	$ 263
Door:	each	2	$100	$ 200
			TOTAL - CORE:	$1,272
SECONDARY AREA				
Walls:	cu. yd.	24.8	$ 65	$1,609
Roof:	cu. yd.	9.5	$ 71	$ 673
			TOTAL:	$2,282
EXPANDED AREA				
Wall:	sq. ft.		$ 2.41	
Roof	sq. ft.		$ 2.19	

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13. ABSTRACT

The idea of providing shelters in residences is by no means new or unique. While most of the effort in the past few years has been in support of the community shelter, it is possible with a minimum investment to provide some degree of protection within the home. This report discusses the "response" that can be expected from a conventionally built house to the effects of loadings that will be imposed upon it by a nuclear detonation. It then presents three minimum shelter designs capable of resisting equivalent static loads of 10 PSI. These are of extremely austere design, capable of being built at minimum cost but providing a minimum of habitability.

For the homeowner desiring additional livability features, a series of architectural designs are presented that utilize a hardened core as the basic shelter area with adjacent areas of lower protection that can be used as extensions of the shelter area.

For the homeowner wishing to increase the overall strength of his house, a discussion is presented on how this may be accomplished.

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Small Homes Council-Building Research Council
University of Illinois at Urbana-Champaign
December 1968 60 pages
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A discussion is presented on methods of increasing overall strength of wood frame houses.

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